TDS-87-01

Ontario
Ministry of
Transportation and
Communications

Research and
Development
Branch

Ice Detection and Road Weather Information Systems: A State of the Art Report

TDS-87-01

Ice Detection and Road Weather Information Systems: A State of the Art Report

R.C. Ridley
Operations Research Engineer

Regional Municipality of Ottawa-Carleton

Published by
The Research and Development Branch
Ontario Ministry of Transportation and Communications
Hon. Ed Fulton, Minister
D.G. Hobbs, Deputy Minister

Published without prejudice as to the application of the findings. Crown copyright reserved; however, this document may be reproduced for non-commercial purposes with attribution to the Ministry.

For additional copies, contact:
The Editor, Technical Publications
Ministry of Transportation and Communications
1201 Wilson Avenue
Downsview, Ontario
Canada M3M 1J8

Telephone: (416) 248-7226
Infotex electronic mail: 21: MIN006

August 1987

Technical Report Documentation Page

Ice Detection and Road Weather Information Systems: A State of the Art Report

Author:	Robert C. Ridley Regional Municipality of Ottawa-Carleton
MTC No.:	TDS-87-01
Date:	August 1987
MTC Contact:	Rye Case
Published by:	The Research and Development Branch Ontario Ministry of Transportation and Communications
Participating Agencies/-Client:	
Abstract:	This report primarily represents the "state of the art" of Ice Detection (ID) and Road Weather Information (RWI) systems in North America in 1985. European applications are noted in contrast. The author distinguishes between isolated installations of sensors for detection and management of spot hazards and multiple installations over entire road networks incorporated into a much larger road weather information system. Major suppliers of sensors are listed, existing practice is described and a framework for evaluation of ice detection and road weather information systems is given. The author concludes that North American efforts to test and compare sensors from different suppliers are not extensive enough. Evaluations are seldom done beyond a few seasons. When they are done, they incorporate crude cost-benefit estimates of the reduction in accident and maintenance costs only and, in any case, tend not to be published. The report recommends further effort to improve the predictive ability of current applications through modelling and integration with other data sources. Standards for comparison and a schedule of continuing testing and cost-effectiveness analysis should be developed for current and possible future systems.
Key words:	ice detection, road weather information systems, road maintenance
Comments:	This report documents a project undertaken by the Regional Municipality of Ottawa-Carleton in co-operation with, and with the financial support of, the Ontario Ministry of Transportation and Communications.
Distribution:	MTC Head Office and Regions, Canadian Provinicial Transportation Agencies, large Ontario Municipalities, U.S. State Transportation Agencies, interested individuals.
Copyright Status:	Crown copyright

Table of Contents

List of Appendices	v
List of Tables	vi
List of Figures	vi
Executive Summary	vii
1/ Introduction	1
2/ Concepts of Ice Detection and Road Weather Information Systems	2
3/ Current North American Suppliers of Ice Detection Systems	4
3.1/ Boschung Co. Inc.	4
3.2/ Findlay Irvine Ltd.	6
3.3/ Surface Systems Inc.	6
3.4/ 'Typical' Ice Detection System	7
3.5/ Possible Ice Detection System Extensions	7
4/ Existing Practice	9
4.1/ Literature Review	9
4.2/ North American Usage of Ice Detection	11
4.3/ European Usage	18
4.4/ Summary	22
5/ Competing Weather Information Sources	23
5.1/ Ontario Weather Information Sources	24
5.2/ Weather Information Considerations	27
6/ Elements of Ice Detection and Road Weather Information Systems Evaluations	30
6.1/ Hardware Evaluation	30
6.2/ Information Generation	31
6.3/ Independent Operation	31
6.4/ System Operation	31
6.5/ Effect on Maintenance Operation	32
7/ Potential for Ice Detection and Road Weather Information Systems	33
7.1/ Recommendations	34
Bibliography	35

List of Appendices

A/ Boschung, Technical Specifications 36
A.1/Physical Parameters 36
A.2/ Optical Display on Each Frost Warning Module 36
A.3/Power Requirements 36
A.4/ Electric Cables 36
A.5 Electric Values 36
A.6/ Recorder 37
A.7/ Wire Transmission 37

B/ Findlay Irvine Ltd., Technical Specifications 38
B.1/ Outstation Information 38
B.2/ Telemetry 38
B.3/ Information Update 38
B.4/ Addresses Available 38
B.5/ Power Requirements 38
B.6/ Physical Parameters 38
B.7/ Master Station 39
B.8/ Power Requirements 39

C/ Surface System Inc., Technical Specifications 41
C.1/ Output 41
C.2/ Surface Condition Status 41
C.3/ Sensor System 41
C.4/ Power Requirements 42

D/ Summary of State Field Testing of Devices 43

E/ Early Ice Detection Devices 45

F/ Summary of Ice Detection and Road Weather Information Systems Study Contacts 47
F.1/ States in the U.S. 47
F.2/ U.S. Cities 48
F.3/ Canada 49
F.4/ Europe 49

List of Tables

E1/ Usage of Ice Detection and Road Weather Information Systems x

1/ North American Users of Ice Detection Equipment 12

2/ Itemized Costs of Michigan State Scan System 15

3/ Results of Michigan State Ice Detector Evaluation 16

List of Figures

E1/ Developmental Stages of Ice Detection Equipment viii

E2/ Relationship of Ice Detection and Road Weather Information Systems ix

1/ Typical Ice Detection Systems – Schematic Diagram of Components 5

2/ Finnish Traffic Control System 20

3/ Accu-weather Report Format 25

4/ EUCO-COST 30 Videotex-based RWI Systems 28

Executive Summary

The purpose behind ice detection (ID) and road weather information (RWI) systems is the collection of more precise data on local weather and road conditions in order to improve winter maintenance decisions.

Ice detection systems consist of specialized roadway sensors and complementary weather condition sensors which provide information on local weather and, particularly, road conditions at a specific site.

Such systems can be configured in a variety of ways, the simplest and most common application being at isolated sites where they are designed to warn of known hazards. The complexity of ID systems can be progressively increased to provide more comprehensive, system-wide coverage and integration with other weather data sources to develop so-called RWI systems. The scope and direction of ID and RWI systems development are illustrated in Figure E1.

Throughout this report, the distinction between ID and RWI systems should be noted. Ice detection systems are small-scale systems oriented towards road conditions; road weather information systems are more comprehensive, emphasizing both weather and road condition (as determined by ID equipment). This relationship is illustrated in Figure E2.

Current studies suggest two main North American applications of ID equipment:
– at spot hazard locations on roadway networks, and
– at airports to determine runway condition.

There are currently only three commercial North American suppliers of ID equipment:
– Boschung;
– Findlay Irvine Ltd.; and
– Surface Systems Inc.

Boschung and Findlay Irvine have emphasized the European market, whereas Surface Systems have specialized in U.S. applications. The major users of this equipment are in Western Europe, as may be seen from Table E1 (compiled from manufacturers' claims of the three companies named). North American usage is currently dominated by Surface Systems Inc. (Scan) equipment. Not noted in Table E1 are the number of aviation agencies using ID equipment, however aviation applications occur much more frequently. For example, in North America, Scan equipment has been installed at approximately 73 airports.

World wide, there are at least seven manufacturers of ID and related equipment. In addition to the three North American suppliers, these include the following:
– Vaisala (Finland)
– Riso- Roskilde (Denmark)
– FFV (Sweden)
– VVIS.

Denmark is also developing a system at this time (Malling).

The ID systems currently being marketed in North America are generally similar in terms of their ambient weather measuring ability and system structure, differing mainly in the operation of the crucial road sensors. In this regard, two distinctions exist:
– Scan uses passive road sensors and measurement of capacitance, whereas
– Icelert and Boschung use active road sensors and the measurement of conductance to assess road conditions.

The latter type consist of multiple sensors, some of which can be heated or cooled to determine road condition.

A logical extension to the use of ice detection equipment at isolated locations, which is now technically feasible, is the use of ID equipment and remote weather sensing equipment as part of a much larger RWI system. Such applications are well documented in Finland, Sweden and the United Kingdom, where national meteorological and road administration agencies have collaborated to introduce such systems. The Finnish work complemented their participation in the European Co-operation in the field of Scientific and Technical Research Programme (EUCO-COST), particularly their responsibility for a sub-project (EUCO-COST 30/8) which dealt with the development of road weather detection systems.

Ice detection and RWI systems are therefore used predominantly by 'public' agencies and are a component of an overall maintenance or weather advisory system. Ice detection and RWI systems augment the information currently available to agencies from various services.

Weather information in Ontario is currently available from a variety of sources, ranging from the primary source of the data, the Atmospheric Environment Services Section of Environment Canada, to a variety of ancillary private firms and government departments which process these data to develop user-specific

Figure E1/ Developmental Stages of Ice Detection Equipment

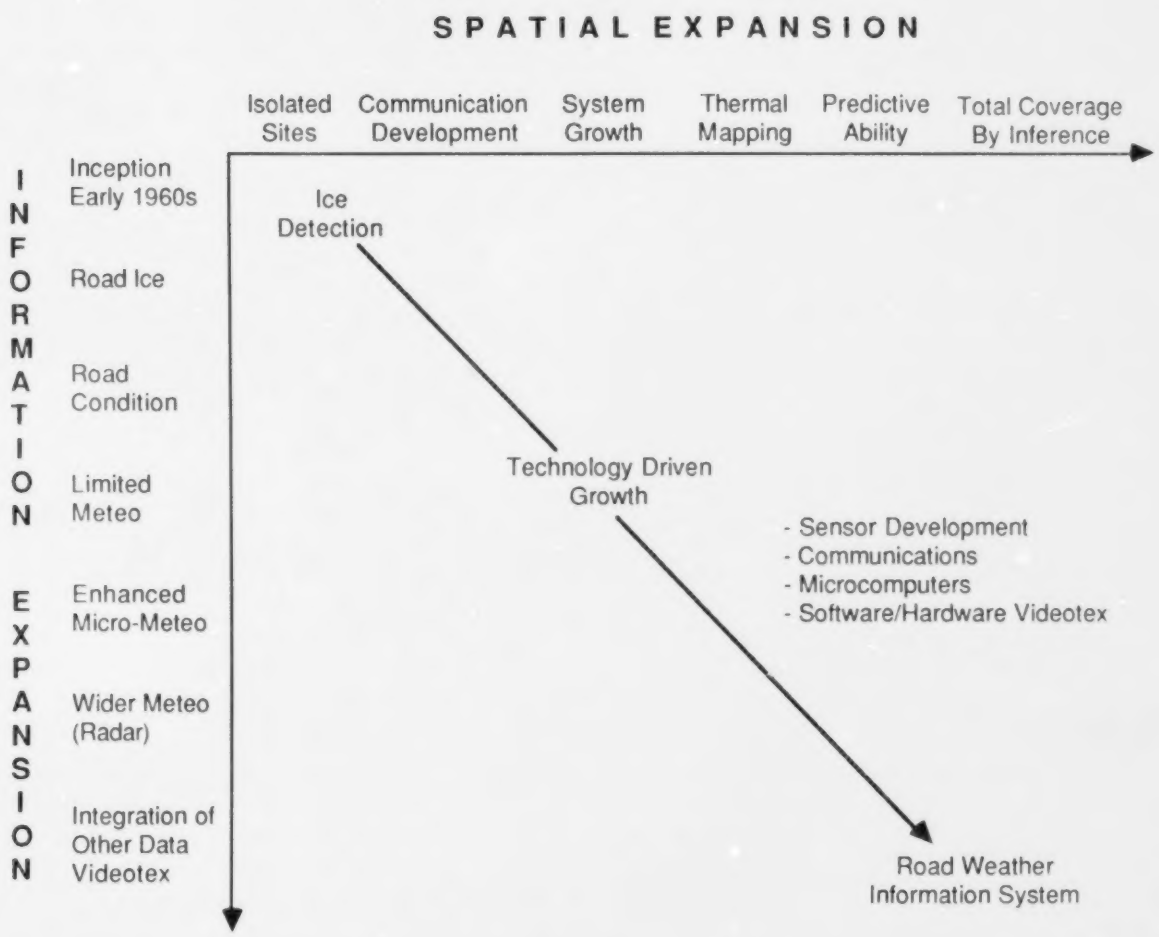


Figure E2/ Relationship of
Ice Detection and Road Weather Information Systems

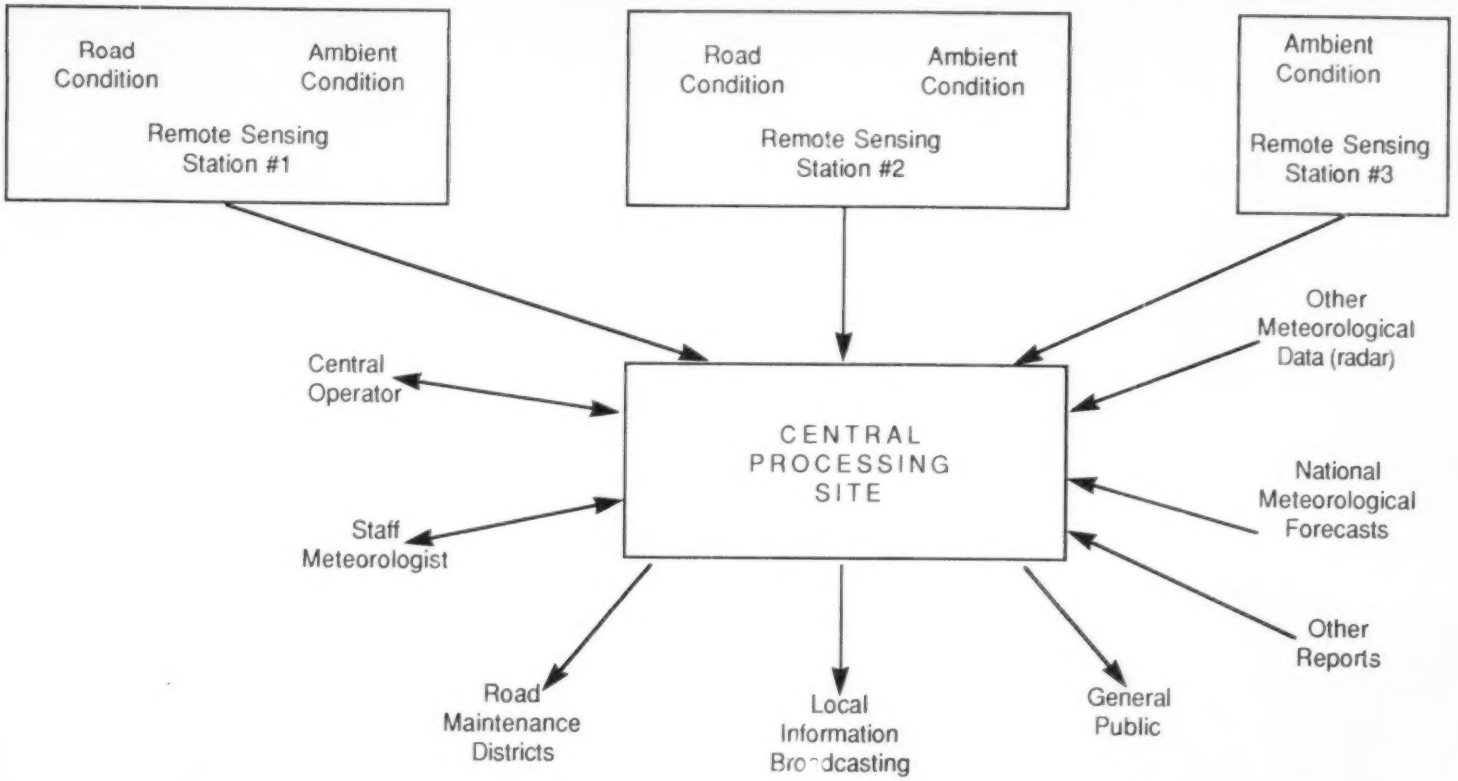


Table E1/ Usage of Ice Detection Equipment By Road Agencies

Country	Boschung*	Surface* Systems	Findlay* Irvine	Total Approx. Users	Total Sensors
Austria	26	–	–	26	
Belgium					
Canada	–	3	2	5	
Denmark†					500
Czechoslovakia	1	–	–	1	
Finland†					100
France †					30
Holland	2	–	–	2	
Iceland					
Italy	–	1	–	1	
Norway†	3	–	–	3	200
Sweden					
Switzerland†	24	–	–		600
United Kingdom	1	2	5	8	
United States	4	16	–	–	8
West Germany	27	1	–	28	
Yugoslavia	4	–	–	4	

* Based upon manufacturer claims and available literature sources (1985, Spring).

† Detailed data for these countries was not available. Sensor usage is that determined from literature sources and/or interviews.

weather information. The data readily available from such sources ranges from real-time weather radar reports to sophisticated forecasts based upon satellite studies. In all cases, data can be manipulated to meet the needs of the end user; however, in general, the result is 'area-wide' as opposed to site-specific and in no case is road condition per se monitored or forecast.

Road condition information is usually collected by road patrols conducted by the agency responsible for road maintenance, and augmented by reports from other sources, such as police agencies. In order to justify the expense of ID and RWI systems, the analyst should quantify, wherever possible, benefits to the agency and to the rest of society. Therefore, evaluation of such systems tends to be oriented to their effect on maintenance operations or safety. Related concerns of information and equipment reliability have also been raised in view of cost, and the liability implications of failures. As with most public expenditures for transportation facilities, a variety of non-quantifiable benefits also exists.

In general, the literature, and the experiences of various users suggest that ID and RWI systems can be cost-effective due to their relatively low cost compared to the cost of maintenance operations, accident liability, and other societal disbenefits caused by poor roadway conditions.

It appears that the cost-effectiveness of ID equipment at isolated spot hazards can be readily proven on the basis of accident reduction, and maintenance savings alone. The cost-effectiveness of the area-wide application of ID equipment as one element of RWI systems, is more difficult to show due to the many non-quantifiable benefits. Such benefits include reduced maintenance cost, reduced system delay, reduced accident potential, and reduced environmental impact. Many other potential side benefits also exist.

Essential to the evaluation of RWI systems is recognition of the fact that they are information systems for decision support. Therefore, the adequacy of current information sources and the enhancement of decisions made on the basis of more extensive information must be considered. Likewise, the intended users of the system must be identified and an appropriate system structure developed.

When reviewed from this standpoint, ID equipment can be justified because it provides information (not available from any other source) which significantly enhances maintenance response. This justification is further enhanced when the benefits of related measures such as thermal mapping of roadways and application of predictive software for road condition are included.

Integration of ID equipment with existing sources of meteorological information to form RWI systems has proven viable in the European context. Various aspects of the European usage of these systems are considered to assess the viability of such integrated systems in the North American context.

Distinctions between North American and European ID and RWI systems users include:
- and meteorological agencies;
- the availability, cost and reliability of weather information;
- the extent to which public access to the system output is permitted;
- usage at isolated locations versus system-wide use;
- emphasis on prediction versus detection;
- the approach to ID and RWI site selection;
- the maintenance decision-making structure; and
- geographical and meteorological differences.

It appears, therefore, that ID and RWI systems can form a viable component of the overall maintenance management system, not on a stand-alone basis, but as a complement to other information sources.

1/ Introduction

In this report, the application of ice detection and road weather information systems to Ontario is discussed. The prime thrust of this analysis is the application of such systems to road maintenance activities.

The following report presents the initial stage of a comprehensive evaluation of ice detection and road weather information system equipment.

2/ Concepts of Ice Detection and Road Weather Information Systems

Ice detection and RWI systems are primarily intended to enhance the decision-making ability of those responsible for roads maintenance. In so doing, it is expected that maintenance activities could be optimized, resulting in improved road safety, reduced cost of service and a better level of service.

Currently, North American maintenance forces function in the following general way:

- Specific personnel are assigned responsibility for the maintenance of certain road sections. Initiation of maintenance is thus the responsibility of local personnel.
- A general weather awareness is maintained to ascertain any developments which may require action. Frequently, weather awareness is maintained by use of specially prepared weather reports purchased from specialized weather services.
- A continuous patrol of the road sections is maintained, emphasizing known spot hazards.
- When impending weather justifies it, or when a road patrol defines a hazard, maintenance crews are dispatched to maintain the road.
- The level of activity, and its timing, are based upon set criteria such as quality standards of manufacturers' recommendations and they are tempered by local experience.

Ice detection and RWI systems can affect all of the above-noted elements of road maintenance operations. Since the systems currently in use are all microprocessor-based, the information collected is accessible via communication links, thus allowing maintenance personnel a much more comprehensive overview of conditions. This permits wider coverage which may be spatial (in terms of specific road section responsibilities) or temporal (as it becomes convenient to maintain awareness of road conditions at other than normal hours). It is expected that development of ID and RWI systems will permit continuous monitoring of road conditions to identify and, one hopes, predict, potential conditions requiring maintenance and, if necessary, alert the staff responsible. This would have the dual benefit of maintaining a constant weather watch, and responding to conditions on a consistent, justifiable basis.

Proper functioning of the system, with strategic placement of the systems' stations, could dramatically reduce the need for continuous road patrols. In this regard, the current ID systems in use can be easily extended both in size, to provide system-wide data, and in complexity, to provide data on other aspects of weather, road or surface conditions. However, the current level of North American exposure to ID systems, and skepticism of their ability based upon historical performance, is not adequate to permit reduction or elimination of road patrols. Such reductions have occurred in Europe due to the greater advancement of their systems and refinement provided by techniques such as thermal mapping.

Many road maintenance activities are dependent upon weather variables. Examples of relevant weather variables include:
- depth and density of snow accumulation,
- wind direction and velocity,
- dew point temperature/relative humidity,
- road surface temperature,
- presence of sunlight,
- type of precipitation,
- current road condition,
- traffic volumes,
- precipitation type, intensity and duration, and
- presence of frost.

Data for many of these information requirements is not currently available from one source, and is generally not available on a site-specific basis. Typically, ambient weather data are collected from one or more sources, while site-specific and traffic-related data are collected by road patrols. As a result, deficiencies exist in the integration, timeliness and accuracy of these data and the resultant maintenance decisions.

Conceptually, the extent of data required suggests that a comprehensive weather information system is appropriate, as opposed to the current data collection as individual components. Development of a comprehensive system would be based upon a network of road and atmospheric sensing stations integrated with existing atmospheric condition services.

It is expected that a network of such stations would provide a very accurate indication of general road conditions, when used in conjunction with appropriate predictive software such as that developed by the University of Birmingham, or the Swedish National Road Administration. Further, ID and RWI systems provide valuable feedback on the necessity for, and success of, maintenance countermeasures. Discussion to this point has centred upon the ability of ID and RWI systems to enhance maintenance activities,

an approach justified by the fact that funding of such systems is typically undertaken by the road authorities.

There are, however, a variety of potential "spin-off" benefits to other agencies, public and government, and the general public at large, in addition to the many benefits to maintenance activities. A partial list of such potential "spin-off" benefits are:

- public relations benefits;
- verification of conventional weather sources ('ground truthing');
- assistance to emergency services such as police and ambulance;
- assistance to public transit;
- data input to other agencies such as environmental groups and forestry officials;
- relief of spot hazards, or more warning of such hazards;
- assistance to other municipal decisions, for example runoff management; and
- integration with other public services.

To summarize, the concept on which ID and RWI systems are based is that of providing a more dependable management tool for maintenance activities. The goal can be partially satisfied by the application of ID systems to verify micro-climate conditions. Full realization of the other spin-off benefits noted requires a more complex integrated road and weather condition information system.

3/ Current North American Suppliers of Ice Detection Systems

Based upon review of the available literature and a variety of North American contacts, it appears that there are currently only three viable North American suppliers of this type of equipment. These are as follows:

- Boschung Co. Inc.; South Holland, Illinois U.S.
- Findlay, Irvine Ltd., represented by Bedix Avelex Inc., Montreal Canada, and
- Surface Systems Inc., St. Louis, Missouri.

The latter two companies have representatives in Canada, while Boschung, which is just establishing itself in North America has a U.S. office only. All companies have been in the ID business for some time, ranging from 12 years for Surface System Inc., to 20 years for Findlay Irvine Ltd.

The systems are of similar configuration, consisting of remote on-site stations and interconnection to a central processing point. The remote sites typically include sensors for ambient weather conditions and one or more road sensors, while the central site includes a computer and associated peripherals. Interconnection of the central and remote sites typically uses leased phone lines. Figure 1 presents a schematic diagram of a system typical of the three manufacturers' systems.

As noted earlier, the prime difference between these systems is the design and method of operation of the road surface sensor and analysis software. It should be stressed that the suppliers noted above are primarily suppliers of road condition sensing equipment. The atmospheric sensing equipment is readily available from many sources and can be purchased from either these or other suppliers. Details of each system follow.

3.1/ Boschung Co. Inc

The Boschung ice early warning system is extensively used world-wide with 92 individual installations comprising over 500 measuring stations, nearly all of which are on road systems. Four North American applications of this equipment are currently in operation or under development.

The primary stated purpose of the Boschung system is the detection and warning of black ice. Black ice occurs when precipitation falls on an undercooled dry road surface, or when water already present freezes due to a cooling trend resulting in a smooth layer of mirror-like ice. This type of icing is a particularly hazardous as it is frequently unexpected and is difficult to detect at night.

The Boschung system is unique in that it is designed to form part of an "Winter Electronic Service" including a thawing agent spray system. The thawing agent spray is activated by the ID equipment and does not necessarily require human intervention to initiate the maintenance response.

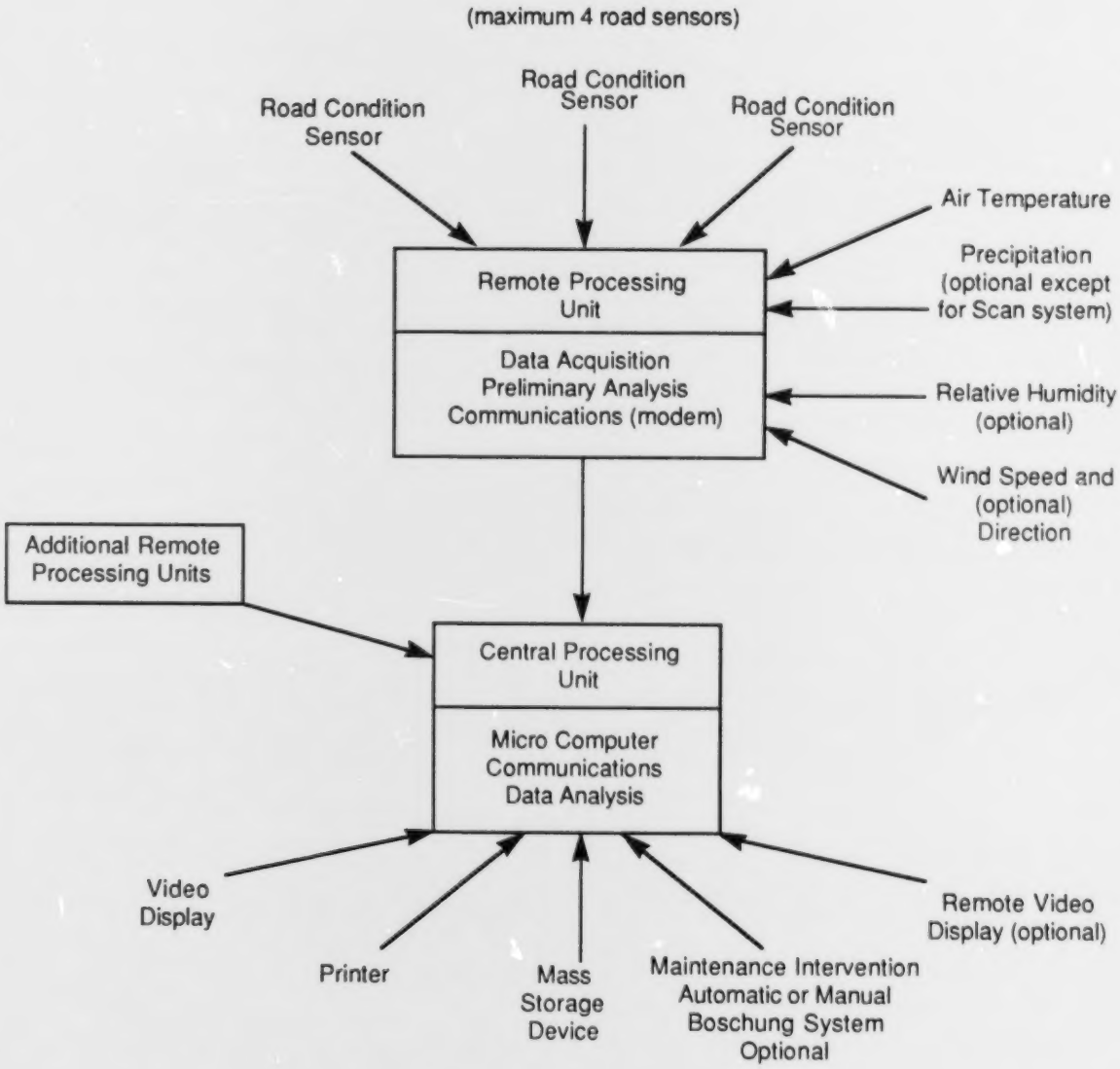
The Boschung system consists of a remote measuring station, comprising up to four surface sensors and various air probes for such data as air temperature, precipitation and, if required, amounts of snowfall. This remote site equipment is connected, via direct lines, leased telephone line or radio communcation links to a central processing computer interfaced with a Texas Instruments Professional computer. Incoming data from the remote site is processed, displayed, and stored for future reference, on the Texas Instruments computer. The central processing unit can only accommodate up to 12 remote stations.

The key element of this system is the ground probe, which is quite elaborate and consists of three individual probes consolidated into one block. The block is installed in the road surface, flush with the top of the pavement. One of the three probes is passive (i.e., no heating or cooling ability) while the remaining two probes can be heated and one can be cooled electronically, using the Peltier junction. The probes measure conductance under various conditions. Since conductance varies depending on the moistness of the road, presence of salinity (thawing agent) and aggregate state solid or liquid of the medium on the road, knowledge of the conductances of the three probes, at three differing temperatures, allows logical conclusions to be drawn as to current road conditions and the possibility of a slippery surface developing. Road surface temperature is measured using a thermistor imbeded in the sensor block.

The inputs of the road sensor probes are analysed using specialized proprietary software to evaluate road conditions and give the necessary alert if required.

Data from this system can be classified in three groups; air data, ground data, and alarms. Air and ground data are continuously recorded at intervals of 10 minutes to provide an evaluation criteria for short-term tendancies. The various alarm levels indicate, respectively, that the presence of black ice due to weather conditions is possible, that black ice will form if

Figure 1/ Typical Ice Detection System – Schematic Diagram of Components



temperature drops due to a lack of de-icing agent or that black ice has formed due to a complete lack of de-icing agent.

As this system is computer based, a variety of reporting formats and/or combinations of data from various outstations can be considered.

The system is readily expandable and can include further meteorological data, from appropriate sensors, such as wind speed, wind direction, barometric pressure, relative humidity, solar radiation, and precipitation quantity. The system is also compatible with weather radar data and the adequate processing capacity to accommodate road condition prediction models.

Recent developments by Boschung include the availability of a new sensor which allows the precise measurement of freezing temperature of the water/salt mixture on the road. The sensor does not require calibration and can be repaired or replaced as required. As noted earlier, the system is intended to warn of ice formation in order that timely application of de-icer can be completed. This capability can be enhanced by adding a thawing agent spray system controlled automatically by the ice early warning system, although such applications are only feasible at spot hazard locations. Further technical specifications are presented in Appendix A.

3.2/ Findlay, Irvine Ltd.

As with the Boschung equipment, the Icelert Mark 4 system is designed to warn personnel responsible for the condition of the road that surface icing is likely to take place if current trends of temperature and moisture persist. The equipment consists of outstations, a master station, and appropriate communication links. The first North American use of this equipment occurred during 1981, at Toronto's Pearson International Airport.

The typical remote installation includes up to four road sensors and an air temperature probe, but can also include wind speed and direction (eight cardinal points only) or dew point sensors. The road sensor consists of three separate sensors combined in one unit and measures surface moisture, surface temperature, salt solution and the presence of ice. The sensors are similar to those of the Boschung system in that they can be heated, cooled, or used passively.

The master station typically consists of three components, a control unit, the information display unit and an alarm unit. The control unit is essentially a modem, or appropriate hardware, to accept data from the remote station. The information display unit includes a microcomputer and appropriate peripheral equipment. The alarm unit uses proprietary software to assess a critical surface condition and activate appropriate audio or visual alarm features. The master station can control up to 32 remote sites. Communication can be via leased telephone lines, but the option is available to use regular lines and have equipment contact the central station only when a specified temperature threshold is reached. Communication costs are therefore reduced.

Findlay Irvine have also developed an Icelert Mark 5 system designed for communication via telephone lines. System specifications have been enhanced to allow each master station to control up to 36 remote stations. Satellite master stations can also be added as required. Each remote station can comprise up to eight road sensors. Data display and storage capabilities are also expanded. Further technical specifications are presented in Appendix B.

3.3/ Surface Systems Inc.

The Surface System (Scan) weather monitoring equipment has been available since 1973 and, as noted, is widely used in North America. In fact, Scan was the only supplier of ID equipment in North America between 1977 and 1981. The standard system consists of electronic equipment at several remote sites and at one central monitoring location. The remote site installation can consist of up to four ground sensors as well as sensors for precipitation, air temperature, dew point, wind speed and direction. The current Scan system is the Scan 16 (Extended Format) system, which has superseded the earlier Scan 7000.

The central processing unit is used to analyse the data collected remotely and is capable of monitoring up to 32 remote sites. The central processing unit is typically interfaced with a printer and video monitor but can include remote terminals or monitors via dedicated line or modem connection using telephone lines.

Likewise, the central and remote units can be interconnected in a variety of ways, including radio link, dedicated lines or standard telephone lines.

As with the Boschung system, the surface condition equipment can be used as part of a comprehensive weather monitoring system including flood sensors, snow depth measurement, colour radar and remote atmospheric sensors.

The unique aspect of this systems is the road sensors which consist of a single unit using capacitance to detect the presence of moisture. The unit is passive in that no heating or cooling is undertaken as in the case of the Icelert and Boschung sensors. The sensor unit is also physically smaller and is matched to the adjacent asphalt in colour, texture and composition to ensure accuracy.

The remotely collected data is analysed by the central processing unit and the road surface conditions are determined as follows:

Dry – no precipitation or moisture

Wet	– wet road above 0°C
Dew	– condensation on road above 0°C
Absorption	– moisture level not hazardous
Chemical wet	– wet below 0°C
Snow/ice alert	– freezing occurring on the road

Computer analysis of the data can also be displayed in a variety of formats, including trend analysis or specialized summaries.

Recent developments by Surface Systems Inc. include a new out station designed for remote use which requires only a central micro processor instead of a central control station. Sensor accuracy has been improved and remote units have been revised to report only to preprogrammed changes to save communication costs. Efforts have also been made to integrate other weather data including weather radar.

Further technical details of Scan equipment are provided in Appendix C.

3.4/ "Typical" Ice Detection Systems

From the foregoing discussion, it is evident that the system structure of all ID equipment available in North America is basically similar. It is appropriate to consider a typical installation.

The typical installation of these devices consists of a central processing unit, usually located at maintenance headquarters, and one or more remote sites.

The central processing unit is microcomputer-based and uses the logic provided by proprietary software purchased with the system. Peripheral equipment includes a printer, video display unit and a mass storage device. Communication with the outstations is accomplished via modem and leased telephone lines.

The remote stations are installed at locations having high accident frequency, or unusual micro-climatic conditions and include at least one road sensor as well as selected atmospheric sensors. The road sensors are embedded on the roadway surface by coring and cutting the surface. All the wiring and sensors are then epoxied in place with the sensors flush with the road surface. Road sensors are direct wired to an adjacent remote processing unit site. The remote processing site includes equipment for data transmission (modem) and the atmospheric sensing equipment.

Typical commercial installation costs for one remote sensing station are in the order of $60 000. U.S. per station, depending on the particular system configuration and size. Operation costs of about $5 000. per year are typical.

3.5/ Possible Ice Detection System Extentions

In the foregoing sections the operation of ID equipment developed by three manufacturers are considered. This equipment can be augmented by a variety of other features beyond the atmospheric sensors typically provided.

These extensions can be grouped in the areas of additional sensing capability, integration with other systems and operation refinements. Discussion of these areas follows.

Many of the jurisdictions contacted add sensors to the remote stations to collect other road/weather related data. Such equipment includes devices to measure visibility conditions directly and to measure the occurrence and depth of precipitation. This latter measure includes the measurement of water depths in runoff areas to assess flood risk. The addition of roadway loops permits the measurement of traffic volume at the remote site as well. Evidence exists of the integration of sensor and micro-meteorlogical data with macro-weather data and forecasts, particularly colour weather radar. Integration of road and weather data permits the use of road surface prediction models as well.

The operation of ID and RWI systems can also be refined by varying the system output. Popular extensions include provision for remote warning of system potential hazards, for example in the homes of maintenance supervisors, in the maintenance vehicles themselves or in the offices of other emergency services. In many cases, modem equipment used for system operation permits remote call-up of the system via telephone. System output can also be modified to develop appropriate detail and "user friendliness" to improve usefulness and acceptance by maintenance staff. In Sweden, voice synthesis is used to relay system output to maintenance staff.

The output of ID and RWI systems can also be used to initiate maintenance countermeasures or motorist advisory signs automatically. The Boschung system, in fact, includes the ability to operate automatic chemical spray equipment to prevent icing hazards. Other applications have used this equipment to actuate roadway heating coils, and in one case heat pumps used to warm a bridge deck. Early applications of ID equipment often included the operation of motorist advisory warning signing, for example "Bridge Deck Icy."

It is clear that a limited number of remote sensors are feasible within a given system. Techniques such as the thermal mapping of roadways permit reliable inferences regarding the total system status to be made from the remote site data available.

Another logical extension of ID equipment is their integration into other large information systems such as comprehensive maintenance management, or weather

advisory systems. Thus, data collected by ID and RWI systems forms an element of a larger data base. Possibilities also exist for the integration of such information into computer-based traffic control systems.

Since the processing capabilities of all current ID systems are based upon microcomputer technology, the possibilities for output format and application are numerous. This situation will continue to improve with the growth and development of microcomputers and communications techniques. Finally, advancements in graphics, hardware and software, for example videotex systems, permit the expansion and integration of ID efforts.

4/ Existing Practice

In order to ascertain the current practice with respect to the use of ID and RWI systems, a survey of available literature sources was conducted. These sources contributed a variety of articles, dealing primarily with the application of such systems to bridge decks in the U.S. The number of articles was relatively low and many were not current. It is apparent that interest in these systems during the late '60s, and early '70s declined, with some re-emergence of interest in the last few years. Interest during the early '70s was no doubt encouraged by FHWA programs reviewing ID systems.

The general lack of documentation regarding North American ID and RWI systems usage appears to be due to the reluctance of many agencies to publish their findings. Documentation of European applications of ID and RWI systems is much better, due to their greater use of such devices and the existence of co-operative projects such as EUCO-COST. Furthermore, European agencies have established the Standing European Road Weather Commission (SERWEC) aimed at co-ordinating research in this area.

Due to the scarcity of current articles, an effort was made to contact known users of these systems to determine if evaluations had been done. This review was primarily oriented to North American users and included review of available literature and telephone surveys. Appropriate contacts were developed from sources noted in the literature and through user lists supplied by the equipment manufacturers. European contacts were developed through the European Road Weather Commission Steering Committee.

The following sections detail the literature reviewed and the contacts made. Due to basic differences in applications, North America and Europe have been considered separately in this review. To show the progress of RWI system development, literature sources are considered chronologically.

4.1/ Literature Review

The origins of ID and RWI systems can be traced back to the early '60s when patents and developmental devices of this type began to appear.

The earliest large-scale formal assessment of such systems appears to be that originated by the FHWA during 1969, which culminated in the report "An Ice and Snow Detection Warning System Feasibility Study – Final Report," November 1971. Prior to this review, there are only scattered references to ID, generally in the form of unpublished, or uncirculated, reports assessing the operation of early systems. Such early reports are typified by those of the Colorado Department of Highways in 1966 and the State of Oklahoma Department of Transportation in 1971. Various magazine articles noted early installations in Kentucky, Michigan, California, Idaho, Wyoming and Pennsylvania.

While the early installations were promising from the point of view of spot hazard elimination, in practice they were found to be generally unsatisfactory for a variety of reasons, including:
- lack of adequate development,
- not rugged enough,
- not reliable,
- not able to survive the highway environment, and
- poor performance.

As noted, early applications of ID systems are well summarized in the report prepared by FHWA dealing with the feasibility of such systems. This report was very comprehensive and included a literature review, contacts with user agencies, a paper study of such systems, and review of previous field testing conducted by other agencies. Details of the findings of this report follow.

The emphasis of ID equipment at that point was clearly directed at the detection of ice, snow and frost occurrence on bridge decks. It was noted that 20 U.S. states had tested, or were currently testing such devices and that usage was also evident in Germany, Japan, Sweden and the U.K. Details of U.S. usage of these devices at that time are presented in Appendix D.

A proliferation of manufacturers/inventors of these devices was evident, with a total of 22 manufacturers found. The various ice detectors produced used combinations of approximately 10 detection methods ranging from current procedures based on capacitance/conductance to exotic methods based upon scattering of gamma radiation.

The various ID devices are briefly outlined in Appendix E; however, it was determined at the time that only six devices merited further study. Of the six, all but one failed before completion of subsequent testing. The study also dealt with a variety of related issues including the distinction between detection and

prediction, cost-benefit analysis of ice detection systems, sensor placement and sensor specifications.

The cost-benefit analysis conducted was comparatively crude, being based upon accident data and system cost only. For the purposes of analysis, it was assumed that an "ideal" ID and warning system existed. In other words, ice never contributed to accidents. Three possibilities were considered – system-wide application to all interstate bridges in Iowa and two isolated applications, one in Virginia and one in Michigan. Yearly benefits were determined to be $310. to $870. per bridge system-wide and $1430. to $6460. per isolated location (recall that this report was done in approximately 1970).

With respect to the sensors themselves, the report suggests installation should be in the most hazardous location on the roadway, that is, between the wheel tracks of the least used traffic lane.

Consideration of the conclusions of this report is very instructive in describing the early status of ID systems. Salient aspects of the conclusions follow:

"Despite widespread interest ... there is still insufficient knowledge available concerning the relative or absolute effectiveness of the various ID systems."

"Systems exist for ice and snow detection which, if properly installed and adjusted, are capable of reliably detecting ice or snow and give acceptably few false alarms."

"No system has yet proved to be reliable frost detector ..."

"Prediction and detection systems are probably not precise enough at the present time to be relied upon for motorist's warning ..."

"Yearly benefits to be derived by installation of reliable ID systems on carefully selected bridges may range from $1000. to $10 000. However, the yearly benefit per bridge may be only on the order of $300. to $1000. for systems installed randomly or indiscriminately. Thus it is important here ... to use proper engineering judgement'.

Generally, it was concluded that much further testing and information exchange on this subject was necessary.

Subsequently, in August 1975, another report on this subject was prepared for the FHWA entitled "Snow and Ice Detection and Warning Systems". This study was more pragmatic and involved the acquisition and field testing of three of the then most promising, commercially available (in the U.S.) ID systems.

These were the Holley, Cytronics and Scan systems. Two examples of each were installed in a California bridge deck and evaluated over two successive winter seasons (1973/74, 1974/75). The detectors were used to actuate motorist warning signs and the effect on driving speeds was noted.

The results of this study are typical of other early applications of these devices; notably, they were disappointing due to frequent electronic and mechanical failures, and the need for frequent modification, recalibration and testing. After the first year's testing, it was stated that "none of the detectors tested was sufficiently reliable or accurate to operate a motorist warning system in their current state of development". Between the two test seasons, lab work was done to improve the devices. During the final season's testing the Scan system appeared to function best but, still, problems of missed and/or false claims were noted. It was also noted that the road sensors required with the test systems were susceptible to damage from tire chains and settlement. Settlement resulted in water ponding on the detector and loss of reliability.

This latter FHWA report concluded that "...it was doubtful that direct snow, ice or frost instrumentation at reasonable cost, can be perfected to accurately forecast or sense snow, ice, slush and frost on a bridge structure."

It was also noted that extreme accuracy was essential if these devices were used in conjunction with motorist warning signs due to the necessity of transmitting consistent information.

Finally, the variance of conditions over the bridge deck was given as a further drawback of spot sensing, which underlined the need for multiple sensing locations. Likewise, the need for associated environmental sensing was noted to develop composite hazard sensing abilities.

More recently (1979), the status of the Bridge Ice Detection Program at FHWA has been summarized by J.C. Leifer. The results of the above-noted earlier FHWA programs are noted, as well as those of a test of the Scan equipment initiated at the Fairbank Highway Research Station in 1977. This test was favourable, although problems of false and/or missed alarms were still evident. No damage of the sensor heads was evident and operation was reasonably reliable.

Three distinct disadvantages of embedded-in-the-road sensors required for this type of system were noted:

1/ The sensor is susceptible to damage from maintenance equipment, tire chains and studs and is in a generally abrasive environment.

2/ The conditions sensed by the detector and those observed by the driver may be different due to the sensors' location beneath the precipitation and the presence of de-icing chemicals.

3/ The sensor is able to monitor only a small local area

which may experience conditions different from those elsewhere on the deck.

For these reasons, the development of an area sensor was considered necessary. This need led to the attempted development of a system based on radiometry by Lockheed, Missile and Space Co. during 1969. This was not finalized.

The current status of ID in the United States was summarized by the FHWA in a 1985 report by the Experimental Projects Program. This report deals solely with the Scan System, Scan being the only supplier with equipment in operation in the U.S., at that time. More recently, FHWA have noted the availability of Boschung equipment.

The report is based upon the experience of nine state highway agencies and one city that had used Scan equipment. Scan systems used included seven Scan 7000, now superseded, and six Scan 16 (the current Scan system).

Of the seven states using the Scan 7000, only two reported good reliability (average reliability was approximately 85%) while the remainder indicated dissatisfaction with the device, which was abandoned in one case and replaced with Scan 16 equipment in the other cases.

The Scan 16 installations have all been completed since 1982 and evaluation is still underway. Of the six agencies reporting, one installation is incomplete, one is not working acceptably, one has been relocated to a new site, and the remainder are still being assessed. Generally, the equipment appears to function as designed but other problems are noted:
- higher than anticipated maintenance and operation costs of installed equipment;
- unreliability under certain unusual conditions;
- necessity for human intervention due to unreliability of data and need for interpretation; and
- reliability and accuracy deficiencies.

Because of the problems, and the lack of adequate documented evaluation, questions remain concerning long-term reliability and cost-effectiveness.

The report recommends that no further evaluation of the Scan 7000 be conducted but that agencies using Scan 16 systems be encouraged to evaluate their performance and provide documented reliability studies. They also recommend that future installation of Scan equipment be classified 'experimental'.

Other details of the operation of ID and RWI systems follow in the form of details of studies conducted by various agencies of the operation of such systems.

4.2/ North American Usage of Ice Detection Systems

As evidenced by the literature and discussion to date, ID systems originated in the early '60s and interest grew rapidly until the early '70s, following which interest and application of these systems declined dramatically. This is no doubt partially due to the policies of FHWA, which limited their participation in the funding of such systems during the period of decline. This policy has recently changed to again permit participation in the funding of these systems, which are still classified as 'experimental'.

At the time of the 1971 FHWA report, there were 20 states using or testing these devices as well as the U.K., Sweden, Germany and Japan.

These initial users, plus additional users determined from contacts and literature sources, yielded the list of states and cities which have, or are, using ID systems are listed in Table 1. From the listing, note that there are currently 11 agencies in the U.S. using these devices and four cities. In Canada, only four such systems are in use, two at airports and two by road authorities.

There is evidence of much growth in interest in these systems recently, as ten U.S. states have indicated an intention to implement such systems in the very near future.

The systems currently in use are predominantly based on Surface Systems equipment. Only one application each of Icelert and Boschung equipment currently exist. The states which are developing new systems include two Scan installations, one Boschung installation and one comparison test, between Boschung and Scan equipment.

For the purpose of delineating the development progress of ID systems, and to verify the current state of their development, detailed reviews of applications in five jurisdictions follow.

Finally, common points noted in discussion with other documented users are noted.

4.2.1/ Michigan State (1982, '83, '84)

During 1983, the Michigan Department of Transportation acquired a Scan 16 system for evaluation in order to:
- Evaluate the durability of system components under adverse weather conditions.
- Obtain information on the conditions resulting in bridge deck icing.
- Evaluate methods used to detect formation of ice on bridge decks.
- Determine if detector output can be used to effect a reduction in bridge icing accidents.
- Determine the feasibility of establishing a grid of sensors to monitor state-wide weather changes and initiate salting.

The Scan system used included four roadway sensors and three atmospheric sensors (air temperature, relative humidity and precipitation).

Table 1/ North American Users of Ice Detection Equipment (Roadway Agencies Only)

Place	Experience
United States	
Arizona	One trial installation. Not satisfied. Not cost effective. No current or planned use.
Arkansas	Scan 7000 system implemented. Satisifed.
California	System tried many years ago. Not accurate or reliable. Abandoned. No current or planned use.
Colorado	Scan 7000 system installed on viaduct. Not satisifed. System to be relocated. (Denver)
Idaho	System installed in 70's. Not satisfactory. Abandoned. (Boise) Scan system to be installed 85/86.
	Scan system to be installed 85/86. (County of Ada)
Illinois	Scan 16 system currently in use. (Peoria) Still under evaluation. Scan system installed for trial period. (City of Chicago).
Indiana	Installing Boschung system for winter of 85/86.
Iowa	Cytronics installation 1971. Not satisfactory. Abandoned. No current use.
Kentucky	Dupont Hygrometer tried approximately 15 years ago. Abandoned. No current use.
Maine	Scan 7000 system installed late 70's. (Bangor)
Massachussetts	Scan 16 system to be installed in 85/86.
Michigan	Scan 16 system installed in 1983. (Lansing) Satisfied.
	Scan system to be installed 85/86 (City of Lansing)
	Boschung system installed late 1984. Free demonstration. (Oakland County)
Minnesota	Scan 7000 system installed late 70's. Not satisfied. Abandoned.
Mississippi	Scan 16 system to be installed 85/86.
Missouri	Scan system installed 1981. Very satisfied. (City of St. Louis)
	Had installation with signs. Not satisfied. Abandoned. (City of Springfield)
Montana	Scan 7000 system installed 1980. Upgraded to Scan 16, 1984.
	Scan system installed. (City of Billings)
Nebraska	Trial Scan 7000 system installation mid 70's. (Omaha) Scan 16 system implemented 1984. (Grand Island)
Nevada	Scan 7000 system implemented in tunnel mid 70's. (Reno) Not satisfactory. Upgraded to Scan 16. Relocated for further evaluation.

cont...Table 1/ North American Users of Ice Detection Equipment (Roadway Agencies Only)

Place	Experience
New Jersey	Four Scan 16 systems currently being implemented. (Trenton)
New York	Scan 7000 system installed. (Triborough Bridge and Tunnel Authority)
North Dakota	Trial installation early 70's. Not satisfactory. Abandoned.
Ohio	Scan system installed at one location 1983. Satisfied. (Columbus)
Oklahoma	Two trial installations early in 70's. Abandoned. Proposing to install Scan and Boschung for comparison. (Oklahoma City)
Oregon	Scan system installed in 1981 at three locations. Very satisfied. (Bend, Portland, Quartz Creek) Additional system to be installed 85/86. (Medford)
	Scan system installed 1984/85. (Multinonah County)
Texas	Scan system to be installed 85/86. (City of Dallas)
Utah	Scan 16 system installed. (Ogden)
Virginia	Numerous past trials, all abandoned. Proposing to try Scan in 85/86. (Richmond, Petersburg Turnpike)
Washington	Scan system installed to monitor mountain pass. Satisfied. (Hyak)
Washington D.C.	System installed to activate sidewalk heaters. Satisfied.
West Virginia	System installation attempted but not completed. None in current use.
Wyoming	Trial Scan system installed mid 70's. Not currently in use.
Canada	
Ontario	Scan 7000 installation in Thorold Tunnel, 1978. Unsatisfactory.
	Icelert system on Ottawa-Queensway, 1982. On loan, returned 1983. Partially satisfactory.
Calgary	Scan system installed 1983.
Ottawa -Carleton	Icelert system installed 1984.

The system utilizes a remote processing unit and micro-computer based central processing unit interconnected via leased telephone lines. Installation was quite straightforward and was assisted by SSI staff. Site work in this case amounted to 300 manhours with a further 16 manhours of work to set up the central processor. System costs were $53 665. U.S. as itemized in Table 2.

Evaluation of the system was conducted by comparing information from the system to that collected by visual inspections at the site.

During the two year study period, three software revisions were made, resulting in a total of four study periods of varying durations. During the total operating period of about 18 months, the system was off-line 29 days, due primarily to failures of peripheral equipment. This is a durability rate of 97.5% (i.e., days on line/total possible days). The system also experienced two telephone line failures and four power failures. The only equipment failure at the study site was the precipitation sensor, which failed due to exposure to road salt spray.

The results of the four study periods are summarized in Table 3, which suggests an accuracy rate of about 80 to 90% is probably feasible.

Accident data were also reviewed but results were inconclusive due to yearly climatic variations. A probable slight decline was noted.

Based upon this study, it was concluded that equipment reliability was excellent (particularly when carefully installed) and that some further software changes could achieve a 90% reliability rate.

It was noted, however, that bridge deck icing is, by its nature, difficult to predict and that the system cannot be used to make the decision concerning salting. Rather it is considered a tool only, providing a good source of information at a remote location. System expansion was recommended, as was deletion of the 'experimental' designation for the Scan system.

4.2.2/ Calgary (1983/84)

During 1983, the City of Calgary acquired and installed a Scan 16 system to monitor the occurrence of bridge deck icing on the Calf Robe Bridge.

The installation consisted of two road sensors (one located in the curb lane in both directions) and sensors for air temperature, relative humidity and precipitation. The detector installation includes a remote processing unit which relays data collected to a central site and operates motorist information signing ("Bridge Icy When Lights Flashing"). Communication is via leased telephone lines.

The site was selected due to its accident frequency related to preferential bridge deck icing and due to local conditions which make this location particularly icing prone.

Following implementation, a variety of hardware and software related problems occurred, including:
- remote processing unit failure due to extremely cold weather,
- software problems, frequent 'alerts' due to excessive sensitivity, and
- telephone modem problems such as static on telephone line.

These various start-up difficulties resulted in an approximately two month delay before acceptable operation was achieved. During the initial period of operation, 21 'critical alerts' occurred. Of this total, seven occurred when the bridge deck was dry. The other 14 were legitimate (i.e., the deck was wet and the temperature below freezing); however, only 11 were judged to require maintenance action. It should be noted that the 'surface critical' indication also operated the warning signs. As a result, the signs were frequently activated unnecessarily. This is unacceptable, as studies elsewhere show that this type of signing loses its effectiveness if it is not hazard-specific. Cursory studies when the signs were activated did indicate a substantial speed reduction of as much as 30 km/h. It was also noted that there was initial concern with motorists over-reacting to the signing.

Due to the frequent erroneous indications, it is noted that human input is considered necessary to analyse the surface sensor data prior to activating the signs.

The impact of this system on accident frequency was not determined as insufficient operating experience was available to make a valid comparison.

The system as installed was estimated to cost $77 000., including the overhead warning signs.

Overall, it was concluded that the Scan 16 system appeared to be a workable system but that further exposure to it was required through more test sites. Further test sites are currently being completed, using more Scan sensors.

Maintenance personnel indicated that they felt the potential existed to reduce operating costs associated with monitoring and preventing icy road conditions. It was noted that more surface sensors were required at the test site to increase the system accuracy by providing a better sample of conditions over the bridge deck.

4.2.3/ Halifax International Airport (1983/84)

The only other recent documented usage of ID equipment in Canada is the installation of a Scan system which occurred at Halifax International Airport during 1983.

Table 2/ Itemized Costs of Michigan DOT Scan System (Initial Costs, US$)

System	Costs	Total Package Price
Costs for this system are itemized as follows:		
Remote Processing Unit Package		
1 remote processor in weatherproof cabinet	*	
4 surface sensors with 150 ft. of cable	$2,400. ea	$25,100.
1 air temperature sensor	*	
1 relative humidity sensor	$1,100.	
1 precipitation sensor	*	
1 electronic rack	$500.	
1 modem	*	
Remote Monitoring Site Package		$4,660.
1 video terminal	$1,685.	
1 printer	$1,575.	
2 modems with portable board	$1,400.	
Central Processing Unit Package		$23,045.
1 central CPU	*	
1 tape drive	*	
1 modem	*	
1 CRT	*	
Telephone Service Installation†		$ 350.
Electric Service Installation†		$ 500.
		$53,655.

* Individual component prices not available.
† Monthly costs amounts to $100. for telephone service and $10. for electricity.

Table 3/ Results of State of Michigan Ice Detector Evaluation

Test Period*	Jan-Mar 1983	November 1983	December 1983	Jan-Apr 1984
System indication and road status agree.	115	62	48	86
System indication and road status differ.	32	31	24	17
System indication bad. Road status good.	15	11	14	10
System indication good. Road status bad.	1	1	1	1
Other system errors.	16	19	9	6
Total observations.	147	93	72	103
Calculated accuracy rate.	78.2	67.3	66.7	83.5

* Four test periods resulted from on-going software revisions to improve system performance.

Prior to this installation, Transport Canada had conducted a trial of two ID systems at Pearson International Airport during 1981/82. The systems tried in this earlier instance were Icelert and Scan. As a result of this test, both systems were found to be acceptable and were invited to tender for the Halifax installation.

The system selected for Halifax International Airport was the Scan 16-EF land-based system, including three runway sensors, air temperature and relative humidity sensors, and associated peripheral equipment. Data collected by the remote sensors are sent to two central locations, the Duty Manager's office and the Maintenance Garage. Transmission is done via dedicated telephone lines.

Installation proceeded without problems and was accomplished in two weeks, by a subcontractor.

In the evaluation it was noted that maintenance and operations supervisors were reluctant to use the system for daily operations due to a variety of problems including unavailability of information, communication failure or erroneous status indications. Eventually, the problems were overcome and confidence increased.

The study notes a definite reduction in the use of ice control materials (sand and urea) of approximately 15%. The potential also existed for savings in overtime as the system made it possible to monitor trends in runway temperature and status. (Halifax International Airport does not maintain a 24 hour staff at all times.)

Generally, a better level of service was achieved. The runway condition was continuously monitored and maintenance operations were initiated expediently.

It was noted that the system requires operator intervention for decision-making due to the need to interpret results before initiating action.

4.2.4/ Ontario Ministry of Transportation and Communications

The Ministry installed an SSI Surface Systems ice detector in the Thorold Tunnel in 1978, following a serious automobile accident. Continuing failures of the electronics and false alarms were major causes of the Ministry's dissatisfaction with the system.

In 1982, the Minstry installed an Icelert System on the Ottawa-Queensway. It was returned in 1983, after only partial success.

4.2.5/ Regional Municipality of Ottawa-Carleton

Due to the lack of application of ID systems in Canada, and particularly Ontario, a co-operative project was initiated between the Regional Municipality of Ottawa-Carleton and the MTC.

This project was intended to select, acquire, install and evaluate an ice detector system to upgrade knowledge on the subject.

As noted elsewhere, only three suppliers were found and for cost and availability reasons, Icelert equipment was selected. The system developed is, however, hybrid in that only the road detection sensors, ambient air temperature, and remote processing equipment were supplied bylcelert. The remaining peripheral equipment and ambient weather sensing equipment (wind speed, wind direction and relative humidity) were supplied by other manufacturers.

During acquisition and start-up of the system, some delays were experienced due to supply difficulties and the amount of in-house system development required. The system was finally made operational in early January 1985 at a total equipment cost of approximately $45 000. It is estimated that a similar cost was experienced for installation and system development.

A full system evaluation is to be undertaken on the basis of evaluation criteria noted in a subsequent section of this report. Initial results are, however, promising:

- Very few system failures have been experienced.
- Basic sensor responses appear to be accurate based upon field verification. However, certain logic functions require verification.
- The only equipment-related problem to date has been the inability to calibrate the relative humidity sensor.

A full evaluation report of experiences during the winter 1985/86 is currently being prepared.

4.2.6/ Other North American Usage

In addition to the review of available published data and evaluation reports on ID and RWI systems, an effort was made to contact all current and past North American users of these devices. Officials of the following agencies were contacted:

- Federal Highway Administration
- U.S. Army Cold Research Test and Engineering Laboratory
- TRB Snow and Ice Control Committee

Details of all contacts made are provided in Appendix F of this report. Therefore, what follows is an overview summary only.

It is apparent that virtually all early installations of ID equipment have now been abandoned. The main reasons for this seem to be the development risks and small market for these devices, as well as the basic unsuitability, inaccuracy and mechanical inadequacy of most early detector systems. As a result of industry 'shake out', only three North American suppliers of these devices are currently active, two of which are based in Europe. Due to the limited number of U.S.

suppliers and the need for further evaluation of these devices, the FHWA have requested that projects incorporating either Scan or Boschung equipment be programmed experimental. Icelert is not currently used in the U.S.

Current trends in the development of ice detector systems appear to be in two directions:

1/ Current systems developed since the early '60s, are based on the principle of conductance/capacitance to detect the presence of moisture. These systems require the addition of other ambient atmospheric information to improve prediction accuracy. Suppliers of ID equipment are continuing to develop these systems, principally in the area of software and additional sensing capabilities.

2/ 'New technology' systems are based upon the principle of radiometry and using microwave technology for ID. Such a system was first suggested by the FHWA in 1979 but the prototype was not successful.

A revised system is currently under development (at the theoretical stage) by the U.S. Army Cold Region Test and Engineering Laboratory.

The use of ID equipment is primarily aimed at spot hazards – bridge decks in the case of road applications, and selected runways by aviation users. With few exceptions, all current users of ID equipment are utilizing equipment for such site-specific applications.

In numerical terms, the usage of ID equipment by road authorities in North America has declined dramatically, with only 11 states and four cities currently using these devices in the U.S., and only two road jurisdictions in Canada. This number is expected to increase by ten users during the 1985/86 winter season due to new installations. It should be noted, however, that many more users exist due to the wide application of these devices at aviation facilities.

Scan equipment is the only system currently enjoying widespread use, although there is evidence of the adequacy of the Icelert system and of interest in both the Icelert and Boschung systems.

Current users of ID equipment are generally quite supportive and enthusiastic about the equipment and it is clear that the emphasis has changed from getting equipment which will function to optimizing the use and accuracy of such systems. Early mechanical failures, which plagued the equipment, seem to be substantially resolved.

System use appears confined by its inherent limitations to that of a decision-support tool to be augmented by judgement and/or other techniques and road patrols. This is necessary because currently available sensors detect conditions over a very small area at the selected site, and also because the detectors are physically installed in the road and therefore are below precipitation or other conditions evident to the driver. Finally, the nature of weather, and its effect on road conditions, will likely always result in some inaccuracy.

Ice detection systems, where used, are essentially a maintenance management tool in that the resulting information is not available to motorists. This has occurred because detector inaccuracies detract from the effectiveness of hazard-specific signing, and due to the legal implications involved. In this regard, the FHWA has already recorded one example where court action has been taken as a result of information given on a motorist information sign.

No evidence was found of formal integration of ID equipment and other weather information sources to create RWI systems paralleling European applications. Surface Systems is, however, undertaking a trial program during the winter of 1985/86 involving integration of their equipment and weather data from Global Weather Dynamics Inc., so as to use the predictive road condition model developed by the University of Birmingham.

4.3/ European Usage

As noted elsewhere, there is evidence of early European usage of these devices and of development work. The FHWA report of 1971 noted ID equipment usage in Germany, Sweden, Japan and the United Kingdom. More recently, European interest in ID systems has been focused through the EUCO-COST program. A sub-project of this program has been established to study the relationship between road traffic and weather (EUCO-COST 30, Theme 8).

The project has been underway since the mid 1970s and is largely concerned with the development of a RWI system comprising a number of localized road and weather monitoring stations.

A number of countries have participated in this project including Belgium, the Netherlands, Finland, France, West Germany, Italy, Sweden, Switzerland, the United Kingdom and Norway.

Work has culminated in a demonstration project on the A.13 motorway between The Hague and Rotterdam, where a complete system was installed during April 1983. The demonstration phase closed February 1984.

Initial results of the program indicate that roadway temperature provides valuable input to maintenance decisions as it typically differs from air temperature and therefore complements meteorological data available from national and regional weather sources. On this basis alone, road weather information systems appear to be cost-effective.

Project participants have recognized the need for more research in this area, particularly to assess the merits of competing RWI systems, and to develop

computer modelling techniques by which road temperature trends can be forecast for up to 24 hours.

The direction of European work under EUCO-COST 30 appears to be that of comprehensive road weather service, including detection, prediction, and warning of hazardous changes in visibility conditions, wind speed and gustiness, skid risk and flood risk. A further direction is examination of the problem of short-term weather forecasting and its repercussions on road maintenance, traffic strategy and the identification of bad weather spot hazards.

These aims necessitate a comprehensive picture which cannot be gained by isolated road stations alone. Therefore, close co-operation is required between the regional or national weather service and the maintenance/highway authority. The comprehensive road weather information systems are oriented to both the road user and the maintenance forces.

Based on available literature, the European leaders in RWI systems appear to be Finland and Sweden (it should be noted that Finland was responsible for co-ordination of EUCO-COST 30 Sub-Project 8). The Netherlands use ID equipment on the basis that it should assist highway authorities to minimize the effects of icy road conditions.

Discussion of the application of ID and RWI systems in Sweden, Finland and the Netherlands follows. General comments on the apparent status of European use of these devices is then provided.

4.3.1/ Sweden

In recent years, Sweden has embarked on a programme intended to develop new RWI system. This initiative was taken due to the inadequacy of existing ID systems and problems of integrating existing systems with maintenance operations.

The extensive use of roadside monitoring stations is considered necessary because conditions vary dramatically over the road network, and the availability of accurate weather forecasting information is limited. Development of the system is being done by the Swedish National Road Administration, which is the agency responsible for initiation of road maintenance activities.

Weather stations for this system have been installed in the past three to four year period and expansion is planned to continue over the next five years.

Currently, the system consists of 170 outstations and eight central units comprising a computer, speech synthesizer, tape recorder and printer. Communications include electronics to adapt data collected to the public telephone network.

Outstations typically measure road surface temperature, air temperature and air humidity. Some stations also measure wind speed and direction and the presence of moisture. The sensors themselves are of Dutch manufacture and depend upon conductivity measurement to determine road conditions.

The location of stations is established by comprehensive local climatological studies and local experience as to where ice conditions first develop. It is noted that outstations are not used exclusively to detect ice due to their limited accuracy in this mode (in Sweden's experience). The presence of moisture and road surface temperature are used to determine when roadway conditions are critical.

Sweden is currently planning to install a new type of ice sensor for testing during the 1985/86 winter season, for evaluation and reliability testing.

The key elements in the development of the Swedish system appear to be the inadequacy of existing road and weather information and the structure of their maintenance operations which result in decisions at a national level. The determination of site location through climatic studies is also interesting.

4.3.2/ Finland

Finnish applications of ID and RWI systems are well documented by virtue of their co-ordinating role on EUCO-COST 30 Theme 8. Investigations of RWI systems began in 1980 with two trials in 1980/81 aimed at establishing a basis for the development and evaluation of these systems. During 1981/82, an operational RWI system was developed. Development responsibility was shared by the Finnish Meteorological Institute (FMI) and the Roads and Waterways Administration. The FMI has operational responsibilities. This system has now been working for three winter seasons.

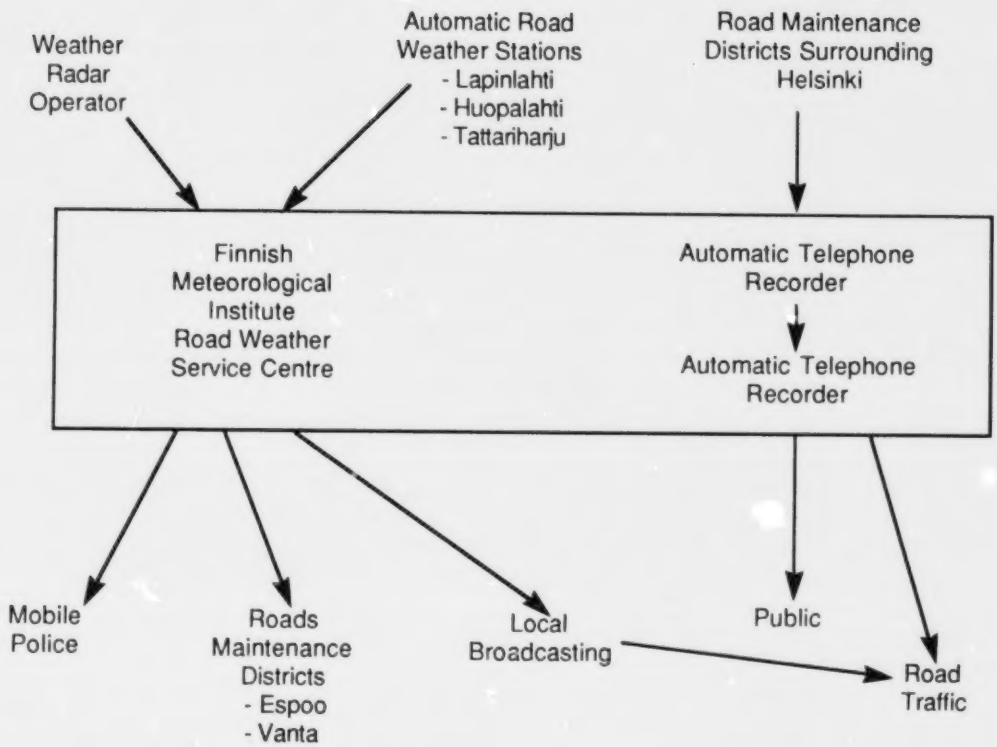
As a starting point, the Finns defined the road weather service as the area weather service, incorporating weather and road condition information and their forecasting, to be rendered to the various parties (as distinct from the area weather service intended for road maintenance districts and called the maintenance weather service).

The purpose of the road weather service was primarily to assist those responsible for road maintenance by providing accurate and timely weather details and forecasts. A secondary purpose was to provide road condition data and forecasts.

The road weather service proposed by Finland, and illustrated in Figure 2 is quite elaborate in that it is part of the overall traffic control system. The system is oriented to both the public (traffic) and road authority (road maintenance).

The most elaborate road weather service experiment was conducted in the Helsinki area with a system configuration which included the following.

Figure 2/ Finnish Traffic Control System



- Three automatic road weather stations (measuring wind, speed and direction, air temperature and humidity, precipitation occurrence, visibility, surface temperature and presence of moisture, asphalt temperature and surface conductivity).
- Weather radar, and a full-time meteorologist.
- Colour display terminals for maintenance districts, police, system operators and local radio stations.
- Automatic telephone answering for outlying maintenance district and public enquiries.

The automatic outstations called MIDAS were developed and produced by Vaisala Ltd. The central computer operates via the MISTEL videotex system. It is noted that reliability concerns necessitated human intervention, especially for icing forecasts and road condition observations. Thus, a full-time meteorologist was on shift to monitor or adjust all system output.

A cost-benefit analysis of this system indicated that it would only be cost-effective in high traffic areas where it could be enhanced by traffic control measures such as changeable message signs. The overall cost-benefit ratio was determined to be at least 1:1 but not greater than 1:4.5, most probably 1:3. Benefits were:
– replacement of maintenance district weather monitors by the road weather service;
– reduced use of salt due to advance salting; and
– accident reduction.

Maintenance and accident benefits were considered to be roughly equal. Other non-tangible benefits such as less stress in decision-making, better planning, improved traffic flow, reduced delay, and lateness were also anticipated.

Many aspects of the Finnish Demonstration in Helsinki are included in the videotex-based weather service system developed under EUCO-COST 30 Theme 8 and described elsewhere.

4.3.3/ The Netherlands

The Netherlands, in common with other west European countries, experience somewhat unpredictable weather conditions, resulting in frequent freeze-thaw cycles and the frequent, sudden occurrence of icy road conditions. This climate necessitates removal of all snow from the roadway and timely initiation of maintenance countermeasures to prevent ice formation.

The development of a large-scale computerized system was initiated in 1970 and, between 1972 and 1983, the Dutch motorway authority equipped various stretches of roadway with experimental equipment.

Experience with this equipment made it evident that the prototype system was not capable of predicting icing in all circumstances because the initial formation of ice at critical locations varied depending upon weather conditions. This deficiency was overcome by the use of trained operators to interpret various remotely collected data and other general weather forecasts to assess maintenance requirements.

Initial experience with the system indicates savings in maintenance activities of about 19%, dependent on the winter season's characteristics. Therefore, it is considered worthwhile to implement a country-wide network for ice early warning.

Issues identified by the Dutch include:

– The necessity of providing reliable equipment and utilizing a system design which can accommodate sub-system failures.
– The desirability of site-specific direct warning to drivers of poor road conditions through automatic signing and advisory speeds (as opposed to current global broadcasts of road conditions).
– Improvement of prediction models for roadway icing.
– Development of stand-alone systems for remote icing-prone locations.
– The need for network extensions to facilitate information transfer.

4.3.4/ Other European Usage

European interest in comprehensive 'road weather' systems is currently strong and much co-operative effort is evident. It is felt that issues such as traffic flow and safety, maintenance and traffic warning systems are affected by road weather – including meteorological, traffic, road and environmental parameters. Generally, road weather service development is considered profitable from the viewpoints of traffic, commercial and socio-economic concerns.

Road weather services in the European context range from the elaborate videotex-based systems of Finland and Sweden to systems essentially based on the concept of a country-wide weather service (i.e., less emphasis on roads and maintenance, more emphasis on motorist advisory).

Such systems are operating in Belgium, Germany, Finland, Italy, the Netherlands, Norway, Sweden, Switzerland and the United Kingdom. Typically, road weather is communicated to the road user via road bulletins, radio and TV broadcasts, and variable message signing.

Many of these systems include, as one component, the installation of ID equipment. It is interesting to note that present-day European systems are not generally used for on-line warning of motorists, partly because of legal implications in some countries.

There are two common elements of the European road weather systems:

1/ The national weather service is involved, and in many cases, responsible for the system.
2/ The systems are oriented to advising motorists of road conditions.

European use of ID equipment also appears to parallel that in North American, namely isolated roadway sections or spot hazard locations. Equipment is available

from a number of sources in the United Kingdom, Switzerland, Finland, Sweden, Denmark and West Germany. One interesting European application of ID equipment is the comparative system testing completed by Denmark. This testing was completed to evaluate the reliability of competing systems, evaluate system warnings and forecasts, and to evaluate application of the systems in de-icing management. The six systems tested were Boschung, Icelert, Scan, VVIS, Vaisala, and an experimental Danish system Riso/Roskilde. The latter system was installed during 1981 and the remainder were installed during 1983/84.

Testing included comparison between each system's output and verification with actual conditions determined by calibrated equipment. These comparisons indicated that all systems deviate from actual conditions, and from each other. Most errors occurred around 0°C. There was evidence of systematic errors in some reporting aspects of all systems except the Vaisala. It was not considered possible to identify any system as superior. Systems were generally reliable, with some malfunctions due to operating inexperience and equipment failure. In addition to functional testing, the systems were reviewed for operational characteristics by simulating maintenance response based on system output. The testing showed that "more of the systems [were] fully sufficient, and that even the best system can only be a supplementary tool, for maintenance personnel, to be considered together with other sources of information."

Unfortunately, this trial has suffered from some criticism due to the study duration (only one week of actual sensor data was compiled) and the study organization.

Many countries using isolated ID equipment appear to have maintenance operations geared to local or district decision-making. Also, it is apparent that climatic conditions in some European countries may lead to more frequent freeze/thaw cycles and the possibility of hazardous roadway icing. Likewise, the size and topographic variation in many European countries leads to significant differences in road/weather condition over the road network. For this reason, there is currently European interest in the development of a writer index to quantify both spatial and temporal weather variations.

It was noted that many countries, including Sweden and the United Kingdom, utilize an elaborate system based upon infra-red techniques to determine sensor locations based upon roadway temperature profiles. The resulting sensor indications, and local experience, are used to determine salt spreading routes.

4.4/ Summary

The foregoing discussion of ID/RWI systems usage underlines the significant differences between North American and European applications. Key areas of difference include:

- the degree of integration between transportation and national meteorological agencies;
- the extent to which the public is directly advised of system output;
- isolated versus system-wide application;
- emphasis on prediction versus detection and the extent of work on predictive modelling; and
- the systematic approach for site selection.

The main reasons for the difference in approach are probably the adequacy of existing weather sources, the variability of weather conditions, the structure of maintenance and meteorological agencies, and the extent of interest/development work in these devices. The physical size of these countries, most of which are similar in size to U.S. states, may also influence ID and RWI usage.

All users appear to be concerned with the accuracy and reliability of ID devices themselves and the resulting legal implications of imparting incorrect data to the public.

5/ Competing Weather Information Sources – Ontario

As detailed elsewhere, there currently exist at least two distinct approaches to the concept of ID and/or RWI systems. These are best described as either spot hazard or system-based approaches. The spot hazard approach is based upon the use of ID equipment, with appropriate associated atmospheric sensors, to detect a specific hazard such as preferential bridge deck icing or runway unserviceability. In this case, the hazard to be detected is generally known and little, if any, predictive ability is necessary. Once a hazard is detected, remedial measures (user advisory signing or maintenance intervention) are initiated. This narrow usage of ID equipment allows equipment to be closely tailored to needs. Accuracy and satisfaction generally improve as experience is gained.

The system-based approach views ID equipment as one component of a much larger comprehensive whole (i.e., RWI systems). The two evident larger systems are the overall maintenance management system, and the broad weather services/advisory function. This is the approach being taken by Finland, Sweden and the United Kingdom.

The spot hazard approach is the basis for virtually all North American applications of ID equipment, due to the historical trend of development and the fact that no North American jurisdictions currently have enough operating ID locations to develop a reliable indicator of system status or weather conditions. Further techniques of extending coverage such as thermal mapping of the roadway are not used.

Depending upon the approach to the application of ID equipment, the issue of competing weather sources may or may not be relevant. Clearly, the application of these devices to warn of spot hazards has little, if any, competition from other weather information sources. Quite simply, this occurs because traditional sources do not provide the information necessary to reliably predict spot climatic conditions and from this assess the hazard potential.

This can be illustrated by consideration of preferential bridge deck icing. This phenomenon can only occur if:
- moisture is present, either on the road surface or in the air over the road surface; and
- the road surface temperature is below freezing.

Such conditions present a hazard because microclimatic and/or topographic conditions result in unexpected icing. Other forms of icing are less hazardous because their presence is more evident to the motorist – for example, snow falling or ice formation due to traffic action. Hazardous forms of road icing include:

Black Ice – precipitation falling on an undercooled road surface and freezing instantaneously (also mirror ice).

Frost – warm humid air flowing over an undercooled road surface forms frost due to sublimation.

Icy Freeze – water present on the road surface freezes gradually due to falling temperature.

The key element here is roadway surface temperature and this information is very site-specific and not available from any existing source. Furthermore, hazardous sites are not always obvious – hence, the need for a systematic approach to identify such locations.

Therefore, consideration of competing weather sources is not an issue for ID equipment installed to ameliorate spot hazards. In fact, current weather sources and ID equipment sources are largely independent for this application.

Competing weather information sources are, however, very relevant to the consideration of ID equipment as part of a larger system for either maintenance or weather monitoring because:

- weather information sources specifically tailored to maintenance needs currently exist;
- the cost-effectiveness of RWI systems is based upon the improvement which such systems offer over current operations;
- dedicated weather information 'experts' familiar with area-wide local conditions are readily available at a nominal fee, as are specific related technologies and services such as radar;
- the current 'predictive' ability of ID and RWI systems appears limited, however, this deficiency is the subject of research by various agencies to develop predictive models for road conditions.

Previous discussion of European RWI systems suggests that such systems are primarily oriented to establishing weather conditions. This added weather information is considered necessary for a variety of reasons, including such things as the cost, availability and reliability of current sources of this data.

In order to assess the potential benefit of RWI systems in Ontario, and in view of the above-noted considerations, it is essential that existing sources of weather information be considered. Any information system must be considered in light of the adequacy of existing data sources and RWI systems are no exception.

5.1/ Ontario Weather Information Sources

Ontario jurisdictions currently have a wealth of sources for weather data. Primary weather information sources to be considered include:

- the weather services of Atmospheric Environment Services (AES);
- specialized maintenance-related weather sources (Accuweather);
- professional observers;
- Telidon Aviation Briefing System (TABS);
- independent weather specialists; and
- miscellaneous sources.

The following sections describe the facilities of each of these sources, and highlight their impact in relation to RWI systems.

5.1.1/ Atmospheric Environmental Services

The facilities of AES are operated by the Federal Government of Canada and provide the national weather services for this country. Data are collected by AES from all traditional sources, including a chain of weather radar installations, satellite overviews, liaison with other national weather services, and observation stations at numerous points across the country. Current information is augmented by thorough historical records.

Weather information is made available in a variety of user-oriented formats ranging from aviation weather forecasts to weather briefings for the general public. Severe weather warnings are also prepared, as appropriate.

While a wealth of general weather knowledge is available from AES, due to manpower limitations and the availability of such services in the private sector, they do not provide a special service aimed at road maintenance operations. Furthermore, traditional weather services provide very little in terms of prediction of weather variables of interest to maintenance authorities – typically, only air temperature is predicted.

Of current interest, due to technology development, is access to AES-operated weather radar sites. Access to date has been quite limited and is confined to various public agencies. Permission has been granted to one commercial venture (Kavouras Weather Technologies) for access to this data but no connections have been made to date.

The radar facilities of AES are currently used by at least two road maintenance jurisdictions, namely the City of Nepean and MTC District 6, and expansion is proposed to include MTC District 9 and possibly the Regional Municipality of Ottawa-Carleton.

Both jurisdictions currently using weather radar are extremely enthusiastic about its benefits, particularly the reliability of short-term forecasts which can be made.

The initial cost of this service is very moderate, of the order of $20 000. for hardware. Annual operating costs are minimal. Potential drawbacks are the training required to make reliable inferences from the system and the need to integrate radar data with other atmospheric condition data to assess such things as duration, intensity and type of precipitation.

5.1.2/ Specialized Maintenance-Related Weather Services

As noted above, extensive weather data are collected by the Canadian and U.S. national weather services. These data are made available to a variety of commercial concerns whose specialty is the development of user-oriented weather packages. One such company, Accuweather, will serve as an example.

Currently, many jurisdictions purchase the services of Accuweather, which provides a specialized maintenance weather service. The annual fee for the service is nominal, approximately $4500. per year.

The service provides daily weather reports tailored to the specific geographic area of interest with additional reports providing updates as appropriate and storm warnings or alerts. Special statements, in terms appropriate for maintenance operations, are also given. Figure 3 illustrates the format of Accuweather reports. The service is very widely used and is the mainstay predictive element for many maintenance forces.

Drawbacks of the service are the currency of information provided and, to some extent, the inability to predict changes associated with micro-climatic or local topographic conditions.

5.1.3/ Professional Observers

In practice, the key to maintenance operations, and weather condition, is the information gathered by direct observation. In the case of road maintenance, such observations are conducted by patrols while weather data is collected at various AES sites.

Such formal direct observations are augmented by the observations of other professional personnel. In the case of maintenance forces, this includes police, other emergency personnel, other municipal staff, other jurisdictions, and other professional drivers.

Figure 3/ Accu-weather Report Format

1. STORM ALERT
2. STORM WARNING
3. UPDATED WARNING
4. SPECIAL STATEMENT
(See Other Side)

ACCU-WEATHER,® INC.
SNOW WARNING SERVICE

JOEL N. MYERS, President
ELLIOT ABRAMS, Sr. Vice President
619 W. COLLEGE AVE., STATE COLLEGE, PA. 16801
For Exclusive Use of Client

OUR NUMBERS
814-237-5802
814-237-0309

STORM ALERT

Time _____ Date _____
Mon Tue Wed Thu Fri Sat Sun
Received by: _____

Dependability of Alert:
- ☐ 5. Excellent
- ☐ 6. Good
- ☐ 7. Fair

Prepare For:
- ☐ 8. Snow _____ Inches
- ☐ 9. Sleet
- ☐ 10. Freezing Rain (Glaze)
- ☐ 11. Rain Turning to Snow
- ☐ 12. Snow Turning to Rain
- ☐ 13. Blowing & Drifting
- ☐ 14. Plowing Operation

Estimated Start Time:
- ☐ 15. At _____ AM _____
- ☐ 16. At _____ PM _____

Additional Comments:

_____
_____
_____

Alert Expires Unless Renewed By
- ☐ 17. Time _____ Day _____

STORM WARNING DETAILS

Time _____ Date _____
Mon Tue Wed Thu Fri Sat Sun
Received by: _____

Type of Storm:
- ☐ 18. Steady Snow
- ☐ 19. Intermittent Snow
- ☐ 20. Flurries or Squalls
- ☐ 21. Sleet
- ☐ 22. Freezing Rain (Glaze)
- ☐ 23. Snow Turning to Sleet
- ☐ 24. Snow Turning to Fr Rain
- ☐ 25. Snow Turning to Rain
- ☐ 26. Ice Turning to Rain
- ☐ 27. Rain Turning to Snow
- ☐ 28. Rain Turning to Ice
- ☐ 29. Blowing & Drifting

Storm Will Begin:
- ☐ 30. At _____ AM _____
- ☐ 31. At _____ PM _____
- ☐ 32. Timing Excellent
- ☐ 33. Timing Good
- ☐ 34. Timing Uncertain
- ☐ 35. No Real Accum Before _____

H. Storm Will End:
- ☐ 36. At _____ AM _____
- ☐ 37. At _____ PM _____
- ☐ 38. Timing Excellent
- ☐ 39. Timing Good
- ☐ 40. Timing Uncertain

I. Storm Duration:
- ☐ 41. Less than 6 hours
- ☐ 42. 6 to 12 hours
- ☐ 43. 12 to 18 hours
- ☐ 44. More than 18 hours

J. Snow Accumulation:
- ☐ 45. Storm Total _____ Inches
- ☐ 46. Add'l Accumulation _____ In.
- ☐ 47. _____ In. by 6 a.m. Today
- ☐ 48. _____ In. by 4 p.m. Today
- ☐ 49. _____ In. by 6 a.m. Tomorrow
- ☐ 50. Two In. by _____ AM _____
- ☐ 51. Two In. by _____ PM _____

K. Storm Probability Potential:
- ☐ 52. _____% Chance of 2" or more
- ☐ 53. _____% Chance of 4" or more
- ☐ 54. _____% Chance of 6" or more

L. Heavy Snow Will Begin:
- ☐ 55. At _____ AM _____
- ☐ 56. At _____ PM _____

M. Heavy Snow Will End:
- ☐ 57. At _____ AM _____
- ☐ 58. At _____ PM _____

N. Snow Type:
- ☐ 59. Very Dry
- ☐ 60. Dry
- ☐ 61. Wet
- ☐ 62. Melting
- ☐ 63. Wet becoming Dry
- ☐ 64. Dry becoming Wet

O. Drifting:
- ☐ 65. None
- ☐ 66. Light
- ☐ 67. Moderate
- ☐ 68. Severe

P. Rain Will Begin:
- ☐ 69. At _____ AM _____
- ☐ 70. At _____ PM _____

Q. Type of Rain:
- ☐ 71. Severe Freeze (Below 26° F)
- ☐ 72. Freeze (26-31° F)
- ☐ 73. Cold (32-35° F)
- ☐ 74. Warm (Above 35° F)

R. Effect of Rain:
- ☐ 75. Turn Snow to Slush
- ☐ 76. Wash Snow Away Slowly
- ☐ 77. Wash Snow Away Quickly
- ☐ 78. Make Roads Icy
- ☐ 79. Icing on Trees/Power Lines

S. Temperatures and Winds:

☐ 80. TODAY

TEMPS	Mon Tue Wed Thu Fri Sat Sun	WINDS
6 AM	_____	Ave Dir _____
Noon	_____	Ave Spd _____
4 PM	_____	Hi Gusts _____
10 PM	_____	

☐ 81. TOMORROW

TEMPS	Mon Tue Wed Thu Fri Sat Sun	WINDS
6 AM	_____	Ave Dir _____
Noon	_____	Ave Spd _____
4 PM	_____	Hi Gusts _____
10 PM	_____	

T. Expected Road Conditions:
- ☐ 82. Main Roads Snow Covered
- ☐ 83. Main Roads Slushy
- ☐ 84. Main Roads Icy
- ☐ 85. Main Roads Icy in Spots
- ☐ 86. Main Roads Wet
- ☐ 87. Secondary Roads Snow Covered
- ☐ 88. Secondary Roads Slushy
- ☐ 89. Secondary Roads Icy
- ☐ 90. Secondary Roads Icy in Spots
- ☐ 91. Secondary Roads Wet

U. Special Problems:
- ☐ 92. Slush Will Freeze
- ☐ 93. Icing at Intersections
- ☐ 94. Icing on Bridges
- ☐ 95. Rapid Change to Colder
- ☐ 96. Localized Flooding

V. Weather Following Storm:
- ☐ 97. Insignificant Flurries
- ☐ 98. Flurries — Little or No Accum
- ☐ 99. Flurries — Statement to Follow
- ☐ 100. Hard Freeze
- ☐ 101. Rapid Freezeup after 4 PM
- ☐ 102. Prolonged Melting
- ☐ 103. Thaw Tonight
- ☐ 104. Thaw Tomorrow
- ☐ 105. Thaw on _____
- ☐ 106. Thaw Today: Freezeup Tonight
- ☐ 107. Days & Nites Below 32°
- ☐ 108. Days Above 32°/Nites Below 32°
- ☐ 109. Very Windy
- ☐ 110. Drifting to Continue
- ☐ 111. Next Storm Threat on _____
- ☐ 112. No New Storms in Site

SPECIAL REMARKS:

_____
_____
_____
_____
_____
_____

©Copyright, ACCU-WEATHER,® INC. 1971, 1978

cont...Figure 3/ Accu-weather Report Format

SPECIAL STATEMENTS

Time _____
Day _____
Date _____
Received By _____
Sent By _____

A. Snow flurries with near or below freezing temperatures will probably be in your area from (1) _____/_____ until (2) _____/_____ . Most will not accumulate, but some may cause a light coating. Be prepared to salt.
(3) ☐ Take no action unless slippery spots actually develop.
Additional comments _____

B. Periods of snow are (probable / possible) between (4) _____/_____ and (5) _____/_____ . There will be little accumulation to perhaps one inch, but even a thin coating can produce slippery conditions.
Additional comments _____

C. A storm expected to give you mainly rain is approaching your area. Conditions are such that precipitation may begin as ☐ snow ☐ sleet or ☐ freezing rain as early as (6) _____/_____ and may continue until as late as (7) _____/_____ before changing to all rain. Temperature will be above freezing by (8) _____/_____ thus ending the ice threat.
Additional comments _____

D. There is a (9)_____% chance of occasional ☐ snow ☐ sleet or ☐ freezing rain before (10) _____/_____ which could coat some roads. Rising temperatures will melt any ice by (11) _____/_____ .
Additional comments _____

E. There is a (12)_____% chance of occasional ☐ snow ☐ sleet or ☐ freezing rain between (13) _____/_____ and (14) _____/_____ which could coat some roads and cause slippery conditions.
(15) ☐ Take action only if slippery spots actually develop.
Additional comments _____

F. Snow between (16) _____/_____ and (17) _____/_____ will be mainly (18)_____ and could accumulate (19)_____ inches with a (20)_____% chance of (21)_____ inches.
Additional comments _____

G. Rain may change to snow for (22)_____ hours before ending. Changeover is most likely at about (23) _____/_____ . Only a light coating to, at most, one inch is (probable / possible), but falling temperatures and present wet conditions may result in icy spots after (24) _____/_____ .

H. A rapid change to colder after (25) _____/_____ may cause water to freeze on some roads. Local salting/anti-skid may be needed.

I. Snow flurries and squalls will be in your area from (26) _____/_____ until (27) _____/_____ . Conditions will be highly variable, ranging from dry with partly cloudy skies to perhaps heavy snow. Best chance for significant accumulation is from (28) _____/_____ to (29) _____/_____ . Most probable accumulation during the following periods:
(30) Mid-6 AM _____ Day _____ (31) 6 AM-Noon _____ Day _____ (32) Noon-6 PM _____ Day _____ (33) 6 PM-Midnight _____ Day _____
(34) WINDS _____ (35) TEMPERATURES _____

J. WORST OF STORM IS OVER. Occasional light snow until (36) _____/_____ will give little or no additional accumulation to at most (37) _____ inch(es). TEMPERATURES — Hi Today (38) _____ Lo Tonight (39) _____ Hi Tomorrow (40) _____ Lo Tom Nite (41) _____ WINDS (42) _____ . (43) ☐ Drifting will continue until _____/_____ .

©Copyright, ACCU-WEATHER,® INC. 1971, 1978

Weather data are similarly verified by observers, an example being reports by general aviation pilots. In both cases, interested members of the public often provide further verification of local weather conditions.

The primary drawback to the dependence upon professional observers for maintenance operations is the general lack of a formal system for the collection and routing of such observation reports. Reports are typically received sporadically in non-uniform format and are often essentially notices of particular spot hazards.

Clearly, a formal network of trained observers giving reliable reports in a uniform manner would parallel the collection of such data by RWI systems. It is not clear at this time whether the reliability, cost and administrative difficulties associated with such a network are comparable to those of RWI systems.

5.1.4/ Telidon Aviation Briefing System (TABS)

The TAB system is a videotex-based system using the Telidon technology developed in Canada. The system is currently oriented to the supply of aviation weather information based upon data from AES. This system is currently being developed and marketed by Meteorological and Environmental Planning Limited, Toronto.

Of particular relevance to RWI systems is the potential to extend this system to provide both weather condition and road condition information. In this case, weather data currently developed from AES sources would be augmented by road condition data from remote sensing stations and observation reports.

Road condition data, which could potentially be integrated, includes present and forecast conditions, specialized conditions such as visibility restrictions, drifting, spot hazards and other traffic-related concerns such as detours and road closures.

This system is conceptually very similar to the current application of RWI systems in Finland and Sweden. In particular, the planned demonstration developed by Finland for the EUCO-COST 30 is nearly identical. In this case, remote weather stations (MIDAS and Teledat) are augmented by Boschung ice detectors and Fumosens visibility detectors; these data and meteorologist reports are displayed in a videotex-based format (Mistel). The system format is shown in Figure 4. Similar systems are under development in the United Kingdom using the Prestel videotex format.

A significant difference is the prediction of pavement surface temperatures for some hours ahead, based upon current data and an energy balance model. The European system is also developed at a national level as opposed to the private development of the Telidon system.

The scope of these videotex-based information systems is potentially enormous, depending upon the number of data sources included. Essentially, such systems include elements of nearly all the road condition and weather data sources noted earlier (ID, AES, professional observers, etc.). Clearly, the drawback of this type of system is likely to be its initial cost, and operational and administrative demands in keeping data on file current.

5.1.5/ Independent Weather Specialists

In addition to the sources noted above, there are many firms engaged in specialized areas of weather research. Generally, such firms tend to be oriented to specialized aspects of weather analysis such as air quality, flood management, watershed analysis and environmental impact assessment. Such firms could also conduct specialized weather related studies for maintenance forces if requested.

5.1.6/ Miscellaneous Sources

Numerous other sources of weather-related data exist; however, generally in a user-oriented form not necessarily compatible with maintenance needs. Examples include weather reporting systems of a variety of federal and provincial governments such as the Ministry of Natural Resources, the Ontario Weather Centre, and the Forestry Department.

5.2/ Weather Information Considerations

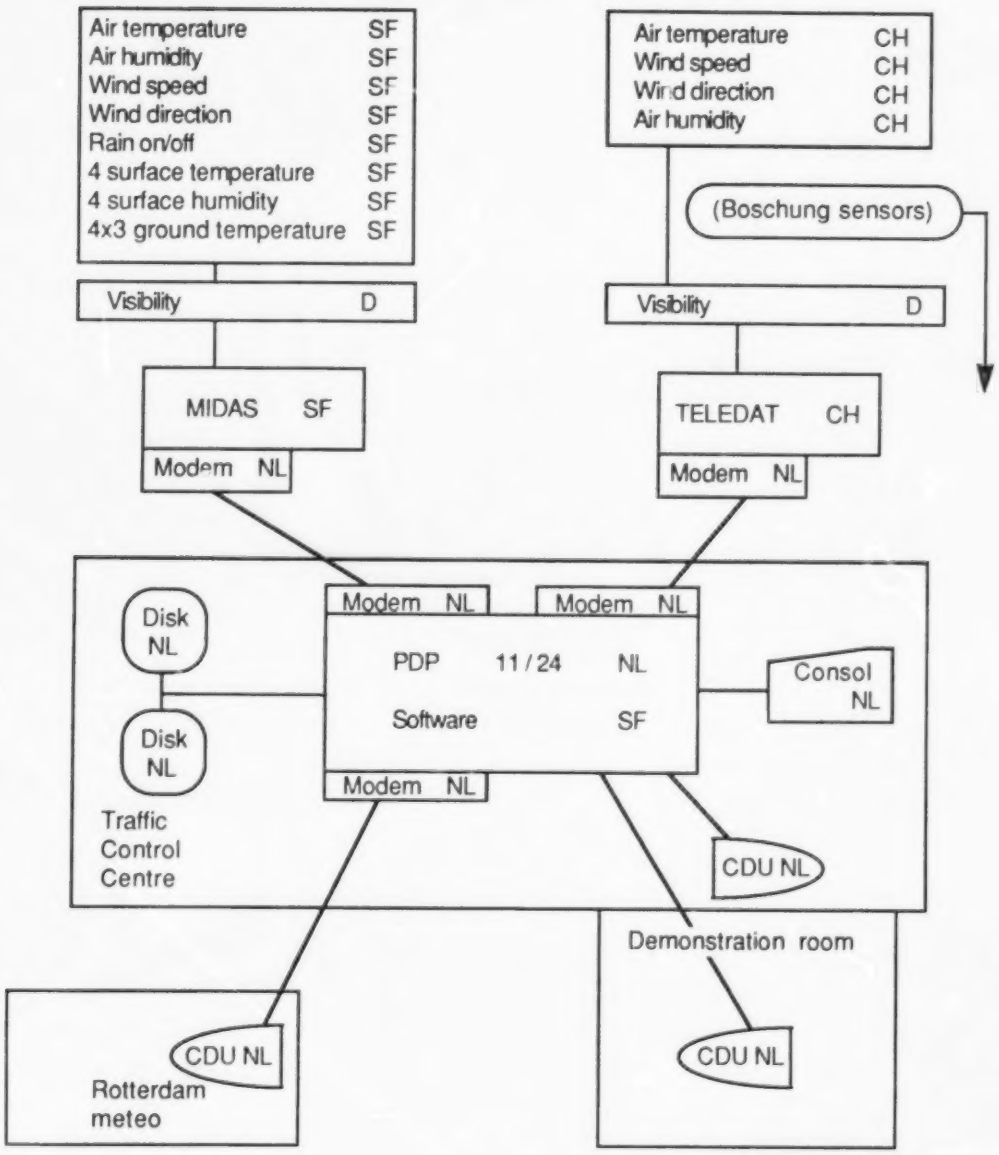
When considered from the viewpoint of maintenance needs, it is evident that a number of elements must be considered in relation to weather information sources. Some of the more relevant concerns include the following.

Information Overload – Weather data are currently available from so many sources that a potential problem of information overload exists. Since maintenance forces are responsible for road maintenance, concise accurate data in the appropriate format is the requirement.

Need – A wide network of atmospheric sensing stations (coupled to road sensing) has the advantage of verifying data from other weather sources. This, of course, is only required if current sources are proven to be inaccurate or inadequate (due to micro-climatic/topographical conditions).

Adequacy – Atmospheric sensing provides current data; road sensing also provides current data although much less reliably. Most maintenance decisions require lead time, making forecast data necessary. Accurate forecasts require access to the wider weather picture and experience in recognizing weather patterns. This may be better handled by existing specialists,

Figure 4/ EUCO-COST 30 Videotex-Based Road Weather Information System



Note: The following contributing coutries are represented with the following codes:

CH - Swiss SF - Finland
NL - Netherland D - Germany

than by attempting to duplicate this expertise within the maintenance area.

Proposed Use – The value of information depends on its ultimate use. The agency responsible for road maintenance must resolve the use of data collected in order to ensure cost-effectiveness. For example, a videotex-based RWI system may exceed the decision-support requirement of most maintenance forces but may be appropriate for a motorist advisory service operated by other public agencies.

Cost Effectiveness – The cost of alternative sources of weather information must be considered in the context of the degree to which maintenance decisions are enhanced by the additional data available.

Administrative Load – Acquisition of weather information from alternate sources imposes an administrative burden on the Maintenance Department. Depending upon the source, technical demands could also increase.

Reliability – The ultimate use of any road condition and weather information is in the support of maintenance decisions. Due to the potential liability, and consequences to the transportation system resulting from errors, it is essential that information be reliable.

Potential Future Development – Certain potential technologies, such as thermal road mapping and the use of predictive models of road condition, appear feasible for future implementation. These technologies, especially modelling approaches, require data of a format and accuracy not currently available. Therefore, technological changes can be expected to significantly alter the demands made on weather information sources.

The role to be filled by road condition/weather sensing alternatives is that currently accomplished by specialized weather information sources (Accuweather, for example) and visual verification of roadway condition (road patrols).

Based upon discussions with road maintenance staff, review of evaluations of ID systems, and review of the operating procedures of other jurisdictions, the following conclusions are drawn:

- The existing system of road patrols is necessary as 'insurance' but reduction in this role may be possible. Other forms of observation, such as increased reliance on police or public advisories, are probably not feasible due to the administrative problems and training necessary to accurately evaluate road condition and develop countermeasures.

- Appropriately packaged maintenance-oriented weather data could replace or augment specialized weather information sources currently used. In particular, radar-based systems appear especially appropriate due to the ease of operation, low cost, ready availability, and accuracy on a region-wide basis.

Furthermore, acceptance of this technology by maintenance staff is good due to its reliability and accuracy. However, due to the limited application of radar technology to maintenance activities, both in North America and in Europe, more accurate assess-

6/ Elements of Ice Detection and Road Weather Information Systems Evaluation

Ice detection and RWI systems are simply systems designed to provide information on which to base decisions. Of particular relevance to this study is the decision concerning roads maintenance. Such decisions are basically unstructured, probabilistic decisions due to their reliance on intuition, common sense, and logic. The outcome of these decisions is more qualitative than quantitative. Generally, applications of information systems to unstructured decisions are as an aid to human decision-making.

The characteristics of information systems depend upon the role they play in the decision-making process, and particularly upon the impact of the information on the ultimate performance.

Evaluation of information systems is typically based upon system attributes, such as the timeliness, content, format and cost of information produced, and system benefits which may be tangible or intangible.

Timeliness is primarily an issue in this case from the viewpoint of currency of data produced and response frequency. Content of information produced is important in terms of accuracy, relevance, exhaustiveness, redundancy and level of detail. It is essential that the level of detail be appropriate for the decision-making stage.

The evaluation of ID and/or RWI systems is somewhat more complex than traditional information systems because of a number of uncertainties – not the least of which has been the lack of clear definition of the type of data required to support maintenance decisions. Likewise, other issues respecting RWI systems are yet unresolved, such as the scale of the system and the end user, although international tendencies do exist.

In view of the foregoing, it is clear that the evaluation of RWI systems can be undertaken from a variety of viewpoints, ranging from straightforward hardware evaluation to comprehensive system analysis. The level of evaluation appropriate also depends upon the application (spot hazard or system-oriented).

Most documented evaluations in the literature reviewed have concentrated upon the operation of ID equipment from a mechanical, reliability and accuracy viewpoint. Little documented evidence of system-oriented, or cost-benefit type analyses exists.

Based upon the literature, discussion with users, and initial evaluation of the ID equipment installed in Ottawa-Carleton, the following evaluation categories appear to be relevant:
- hardware,
- information generation,
- independent operation, system operation, and
- effect on maintenance operations.

The evaluation categories generally follow a hierarchy, the exception being the additional stress on maintenance effects, this being one focus of the current analysis.

The following sections consider the evaluation criteria appropriate in each of the noted categories, and summarize the results of evaluation efforts to date.

6.1/ Hardware Evaluation

Evaluation of ID hardware was the main thrust of most early efforts due to the development infancy of these devices, particularly the road sensor components.

Ice detection systems are composed of four main components:
- road sensing equipment,
- atmospheric sensing equipment,
- remote processing/data transmission equipment, and
- central processing/data receiving equipment.

The technology for all components, except road sensing, is well developed. As a result, such elements are readily available and well proven. However, this is not the case with road sensing equipment (and its associated software).

Appropriate areas of hardware evaluation are considered to be the hardware characteristics, installation considerations, equipment reliability and equipment operation. Further elements can be considered within this framework, which follow approximately the equipment life cycle. Details of specific evaluation criteria are, however, dependent upon the hardware and configuration selected.

Most, if not all, of the early problems associated with ID equipment have now been overcome. The number of manufacturers remains limited, however, and all systems are based upon one of two principles of operation. There is evidence of competition in this field and of development advances. Current users verify that equipment is generally reliable and stands up well in the roadway environment. Problems appear to have

progressed beyond those of the mechanical components and now relate to the logic software used to convert the sensor input to a usable road status report.

To summarize, road sensing equipment now is available from a limited number of suppliers that is capable of reliably detecting road condition, given the inherent limitations of such devices (particularly their small sampling area).

Other system components for data transmission and processing are readily available from numerous manufacturers due to the recent growth of microcomputer technology. One related issue is the capacity of the microprocessor to accept future enhancements such as road condition modelling.

Finally, ambient weather sensing equipment is well developed and widely used. As a result, reliable equipment is also readily available.

6.2/ Information Generation

The information generated by ID and RWI systems ranges widely, depending upon the system configuration. The most basic information could consist of raw data only, for example, roadway surface temperature, presence of moisture or not, presence of salinity or not, and atmospheric data. Such simplistic systems are not generally available as all current manufacturers' systems include proprietary software which assesses sensor input in order to provide an indication of road status. In both cases, current information is portrayed. A logical extension would be the development of predictive modelling techniques to forecast road condition at some point in the future. This latter extension necessitates the integration of other meteorological information and forecasting techniques.

Current systems still suffer somewhat from information generation difficulties inherent to sensor design and placement which limit their probable theoretical accuracy to about 85 to 90%. As a result, jurisdictions usually use the information to augment other sources such as road patrols, or to initiate verification and remedial measures only if staff consider such action appropriate. Likewise, accuracy problems are still considered a major obstacle to the use for ID equipment for motorist advisory purposes, due to the liability implications associated with erroneous indications.

Information from some systems currently in use also suffers from software problems which result in incorrect, or excessively sensitive, interpretation of detected conditions and resulting false alarms.

The development of predictive modelling techniques, and the integration of road and weather information systems does not appear to be well advanced at this time, especially in North America. Predictive models of road condition are expected to become available during 1986 from at least one supplier. Literature disclosed only two, or possibly three agencies working in this area at the current time. These are the Swedish National Road Authority, the University of Birmingham, and possibly one other European agency. Only the model developed by the University of Birmingham is expected to become commercially available.

6.3/ Independent Operation

To date, most North American installations of ID systems have been isolated due to their orientation to specific hazards. The benefits of such isolated usage can be fairly easily quantified and include such things as improved level of service and reduction of hazard-related accidents.

Unfortunately, none of the literature reviewed contained conclusive evidence of accident reduction attributable to such systems. This is due to the random nature of accidents and the fact that road conditions are typically only one factor contributing to accident occurrence. Nevertheless, it is reasonable to assume that ID systems would result in reduced accident frequency.

Level of service improvements occur because spot conditions are continuously monitored – as opposed to road patrols which provide only periodic coverage. Furthermore, evidence of reduced material, vehicle and manpower use exist due to the better surface information available.

Generally speaking, the major benefits of isolated road weather sensing appear to be improved awareness of conditions at remote sites and the potential to alleviate weather-related accidents if appropriate countermeasures are initiated.

6.4/ System Operation

System operation of ID equipment is taken to include integration of remote road sensing and atmospheric sensing devices with other wider systems, for example, area weather advisory and/or the maintenance management systems. In these instances, many more potential benefits exist but quantification is much more difficult. Likewise, system costs are much greater, demanding formal measures of cost-effectiveness.

Benefits in this case accrue to a number of potential system users, including maintenance forces, the general public, public service concerns, emergency officials, and other government departments. A notable benefit would be weather service officials who would gain verification of forecasts through the increased number of remote sensing sites.

Furthermore, widespread availability of road and weather condition information could result in traffic flow improvements (and hence reduced delay) through the knowledge and avoidance of problem locations. Similarly, better emergency response times would be possible. Generally, knowledge of the status of the

overall transportation network would be more accessible to all users.

Finally, it is expected that many of the benefits anticipated for isolated road condition sensing would result, the notable exception being accident reduction. While improved knowledge of area-wide conditions and corresponding maintenance improvements should favourably affect system-wide accident occurrence, the impact could not be expected to be as great as that of a countermeasure against a known accident hazard.

System operation, as adopted in Europe, integrates the service of national road authorities, national weather services and local specialists. Administration thus occurs effectively at the national level. Such integration in North America would necessitate the involvement of two or more levels of government and, possibly, commercial concerns, depending upon the responsibility for development of such a system.

The major costs associated with such a system would be those of any large information system, namely, capital, maintenance and administration costs.

6.5/ Effect on Maintenance Operations

The key thrust of this analysis of ID and RWI systems equipment is to determine its effect on maintenance activities.

This benefit is of prime interest because it accrues to the agency operating the system and therefore has potential budgetary impacts (as opposed to other system benefits which accrue to all road users).

Elsewhere, it has been noted that the major benefits of ID/RWI systems to maintenance forces are reductions of manpower, material and equipment usage potentially possible through more complete 'real time' road condition information. Not noted, but conceptually possible, are further material reductions possible by adjusting application rate to reflect current road conditions, for example, residual salinity.

Since remote sensing stations are essentially remote 'eyes' for the department, and in view of the extensiveness of data which could be collected, reduction or even elimination of road patrols is also potentially feasible.

Another clear benefit of ID and/or RWI systems is the improved level of service which results from early warning of road conditions and the improved consistency of decisions made under less uncertainty.

While the effects during winter conditions have been considered foremost (as appropriate for ID equipment), the provision of RWI systems may impact maintenance activities at other times of the year.

At their current stage of development, RWI systems have not achieved many of the noted benefits, partially due to poor acceptance by maintenance staff and partially because development (particularly the development of predictive models of road condition) has not progressed adequately. In effect, current information systems appear to be perceived as adequate, reducing the demand for improved weather data.

It should be noted, however, that benefits could be realized if ID systems were able to merely duplicate existing information sources by virtue of the potential cost savings, reliability and consistency of such a mechanized approach.

7/ Potential for Ice Detection and Road Weather Information Systems

Consideration of the potential for ID and RWI systems must initially address a number of significant issues related to system status in order to place the evaluation in perspective.

Information reviewed for the preparation of this report has defined four major issues:

1/ Clearly, two distinct applications of ID equipment exist, namely isolated installation aimed at spot hazard locations as used in North America and some European countries, or system-wide installation as an integral part of a road weather advisory service as used in Finland, Sweden and the United Kingdom. The fundamental issue here is not necessarily the system size, rather the degree of integration of ID data with other relevant weather data sources.

2/ The primary system focus must also be established. Again, two possibilities emerge: current systems have as their focus either the support of roads maintenance activities or the support of a much wider user group including particularly general road users (the public).

3/ Depending upon the focus of the system, and the application proposed the need for, or adequacy of, detection as opposed to prediction becomes evident. In many instances, detection may be adequate (e.g., the knowledge that road conditions are currently bad, or will become so very shortly), whereas wider system demands may necessitate predictive abilities ranging from a few hours to a full day.

4/ Finally, any system for ID and RWI is merely an information source. Therefore, it is essential that the adequacy of current information sources be eval uated and a cost-effective choice selected, based on the resulting quality of decisions made under current or improved information availability.

Notwithstanding this, the following conclusions are made with respect to the current state-of-the-art of ID and RWI systems:

- The current directions of ID and RWI systems' application have occurred because of one or more of the following reasons:
  - the structure of the maintenance department and especially its decision-making process;
  - the adequacy of available weather data sources;
  - the perceived adequacy of ID equipment;
  - the feasibility of integrating road condition and weather condition sources; and
  - the predictability of weather/road conditions.
- North American suppliers of the road sensor component of ID systems are very limited and inadequate testing, or comparison, of these sensors has been made. Only one ID system, Scan, has been used extensively in North America and the current model Scan 16-EF has not been available long enough for proper evaluation.
- North American suppliers of weather condition sensing equipment, and all other related RWI system equipment such as the microcomputers and communication hardware are plentiful. This equipment has also proven reliable and is well accepted by users.
- Current ID road sensing hardware appears to function, at least initially, as designed. Durability over extended periods cannot be evaluated as no extended use systems exist.
- The ultimate accuracy of the road sensor component of ID systems is than perfect, probably 85 to 90%, due to the drawbacks of current technology, in particular the small surface area of the sensors.
- Road sensor placement, while critical to the operation of ID equipment, is unresolved at this time. Selection of sensor locations within the road network, and the specific location on the roadway surface are currently established by subjective criteria, especially in North America. European countries appear to exercise a more systematic approach to site selection based upon infra-red techniques.
- The orientation of evaluation efforts to date has been either verification of road sensor operation or crude cost-benefit analysis based upon potential accident reduction and maintenance benefits. Evaluations of any type are limited and most are not published.
- The current predictive ability of ID equipment and software is poor to non-existent. Development of such ability is currently in its infancy, although European users appear to be ahead of North American jurisdictions in this regard.
- Ice detection equipment appears to be most effective when used for applications at known hazards

and locations where micro-climatic and topographic conditions are unpredictable.

- Certain current North American weather information sources are not used effectively, particularly road advisories by other professional staff, and radar detection systems.

- Operational characteristics of ID equipment, and the possibility of legal liability, limit the potential of remote road condition sensing.In particular, while road patrols can potentially be reduced, the elimination of such patrols and the use of such equipment to activate motorist advisory or maintenance countermeasures devices do not appear to be feasible with the existing technology.

7.1/ Recommendations

The lack of current North American exposure to ID systems, and divergence of approach regarding ID and RWI systems between Europe and North America, suggests a number of directions for further effort aimed at clarifying the potential for this equipment. These recommendations are:

1/ Existing North American ID system installations should be monitored over an extended period to determine the long-term reliability and accuracy of the equipment.

2/ Assessment of competing suppliers of ID equipment should be made to encourage development of these devices. This should include recognition of European efforts in this field and efforts to collect detailed data regarding their experience.

3/ Application standards should be developed to encourage consistent usage and comparability of ID systems in use. Specifics should include installation and equipment specifications, operating protocols and guidelines for site selection. Again, recognition of European efforts is necessary.

4/ Future evaluations should stress tangible benefits to accident reduction and roads maintenance operation, which will be quantifiable with extended system operation.

5/ The feasibility and benefit of using other sources of weather information, particularly radar, to complement the data available from ID systems should be assessed.

6/ The feasibility of 'new technology' approaches to overcome the drawbacks of current ID equipment should be evaluated.

7/ An effort should be made to improve the predictive ability of current ID technology, through appropriate modelling approaches and integration with other data sources.

8/ Further analyses should be undertaken to refine the cost-benefit ratio of RWI systems in the North American context.

Bibliography

Bell, G.H., "New Aids on Winter Traffic Control," Public Works, August 1975. Road Weather Service Department, Swedish Ministry of Communications, Helsinki, 1982.

Boucher, R., "Evaluation of Surface Sensor System, Scan," Maine Department of Transportation, 1983.

Brinkman, C.P., "Highway Ice Detection," Transportation Engineering, November 1977.

EUCO-COST 30 Theme 8, "The Development of an Automatic System for Observing, Forecasting and Warning of Adverse Road Conditions Due to Bad Weather," Helsinki, August 1979.

FHWA, "Summary Surface Systems Inc. Ice Detection and Warning System," 1985.

Fox, N.K., "Development of a Frost and Ice Detection System for Highway Bridges," TRR 576, 1976.

Glauz, W.D., et al., "An Ice and Snow Detection and Warning System Feasibility Study," FWHA, November 1971.

Griffiths, O.E., "Evaluation Report on the Ice Detection System Installed on the Deerfoot Trail Freeway," Calgary, May 1984.

Hanson, F.R., "Driver Awareness of Highway Sites with High Skid Accident Potential," FHWA, July 1974.

Howard S. White Ltd. for the Ontario Ministry of Transportation and Communications, "Applications for Microelectronics in the Highway Engineering, Operations and Maintenance Processes," TS-84-01, August,1984.

Leifer, J.C., "Present Status of the Bridge Ice Detection Program at FHWA," TRB Special Report 185, 1979.

Levitsky, W.V., "Runway Ice Warning System, Halifax International Airport," Transport Canada, June 1984.

MacWhinney, R.C., et al., "Snow and Ice Detection and Warning Systems," FHWA, August 1975.

Nelson, T.I., "Ice Detectors and Information Signing," Oklahoma Department of Transportation, October 1975.

Oloffson, I., "The Swedish Experience of Road Weather Systems," Speech to Second International Road Weather Conference, Copenhagen, 1985.

Overall, W., "Electronic Roadway Monitoring, The State of the Art in 1985," presentation to AASHTO 1985 Annual Meeting, Seattle.

Ponting, M., "Weather Prediction Systems," Highways and Transportation, November 1984.

Perry, A.H., et al., "Developments in the Techniques of Combatting Winter Hazards on European Highways," University College, Swansea 1984.

Perry, A.H., et al., "Automatic Detection and Warning System of Adverse Weather Conditions for Road Traffic," Finnish Meteorological Institute, 1982.

Perry, A.H., et al., "Weather Systems in the Demonstration," Finnish Meteorological Institute, 1982.

Perry, A.H., et al., "A View Data Based Weather Service System for Road Maintenance and Traffic," Finnish Meteorological Institute, 1982.

Perry, A.H. et al., "Road Weather Information Systems, Swedish National Road Administration, 1982.

Perry, A.H., et al., "Proceedings of International Seminar on Electronics and Traffic on Major Roads," Paris, France, 1985.

Simansen, P., "The Danish White Spot Programme," Road Directorate, Denmark, 1984.

Spica, F.M., "Scan 16 – Moisture, Frost, Ice Early Warning Systems," Michigan Department of Transportation, October 1984.

Spica, F.M., "Computer Used in Michigan Winter Maintenance Operations," Transportation Research News, May-June 1984.

Thornes, J., "The Prediction of Ice Formation on Roads," Proceedings of PTRC Summer Annual Meeting, University of Sussex, England, 1984.

Appendix A/ Boschung –Technical Specifications

A.1/Physical Parameters

A.1.1/ Indicator (Steel Case)

– Stove enamelled.
– 52 x 26 x 27 cm, 11.5 to 13 kg.

Main Module – Electricity supply including voltage selector, main switch, one voltage control lamp and mains cables.

Frost Warning Module – Analog indicators for air temperature and relative humidity, digital indicators of road temperature and humidity, three alarm lights, and a function-checking button. A second is available for independent monitoring at a second site.

Acoustic Module – Acoustical indication of the various alarms with an 'alarm received' button, a selector for reduced acoustical indications, and a switch to turn off the acoustic warning.

Socket Module – Connections for two separate frost warning units, one snow warning unit, one multiple channel recorder and one transmitter.

Snow Warning Module – A function-checking knob, an alarm lamp, and a snowbox for measuring snowfall. Snowbox, 36 x 19 x 26 cm, with 100 ft. cable, 6 kg.

Combined Recorder and Program Module – A 6-channel compensating recorder and 12-programming plugs or one program module with a plug-board and 12-programming plugs.

A.1.2/ Air Probe

Housing and transmitter for precise measurement of air temperature and humidity, 26 x 41 x 14 cm, weight 3.2 kg.

A.1.3/ Surface Detectors

Measure surface temperature, humidity and the onset of ice formation.

A.1.4/ Transmission

Using an analog data transmission unit consisting of a transmitter and a receiver, all signals gathered at the measuring site may be transmitted in analog form over one telephone line to the control centre. These signals and alarms may be transmitted in optical or acoustical form over distances up to 60 km.

Using an analog or digital data transmitter and receiver unit, six chosen optical or acoustical signals or alarms may be transmitted by radio over distances up to 30 km.

A.1.5/ Detector Cable

Maximum 3200 ft., 10 kg per 330 ft.

A.2/ Optical Displays on Each Frost Warning Module

Air Temperature – In Celsius as an analog signal.

Relative Humidity – In percent as an analog signal.

Surface Temperature – As a digital signal (yes/no) when the temperature reaches 0°C or any other predetermined value.

Surface Humidity – As a digital signal (yes/no) when the surface is damp, wet, or snow covered.

Alarm 'Air/Road' – When the air temperature sinks to 0°C and the road is damp, wet, or snow-covered.

Alarm 'Road' – When the surface temperature sinks to 0°C and the road is damp, wet, or snow-covered.

Alarm 'Ice' – When ice formation sets in at the monitoring site.

A.3/ Power Requirements

Indicator – Must be in a dry, sheltered and fairly warm room not more than 1,000 m from the detectors. Supply voltage of 220 or 110 V must be available.

A.4/ Electric Cables

Main cable	10 ft.	2 P + E
Road detector cable	40 ft.	G51, 3 x 2, 0.6
Detector cable	max 3200 ft.	G51, 6 x 2, 0.6

A.5/ Electric Values

Main voltage – 220/110 V, 100 VA, 50/60 Hz
Internal voltage – 2 x 15 V ≂ und 1 x 40 V

A.6/ Recorder

Power supply	110 V internal
Number of channels	6
Recorder systems	compensating recorder
Input	asymmetric
Impedance	high resistance 20-100
Max-deflection	50 mV
Paper	folding paper
Width of scale	60 mm

Item	Transmitter	Receiver
Dimensions	52 x 30.5 x 27 cm	52 x 30.5 x 27 cm
Weight without transmitter	14 kg	14 kg
Main cable	2 P + E, 3 m	2 P + E, 3 m
Power supply	110/220 V 50/60 Hz, 20 VA	110/220 V 50/60 Hz, 20 VA
Internal power supply	1 x 40 V, 2 x 18 V	1 x 40 V, 2 x 18 V
Number of channels	8	8

A.7/ Wire Transmission

Normal frequency range (1)	420-3180 Hz	420-3180 Hz
Special frequency range (2)	3300-5190 Hz	3300-5190 Hz

Output and Input Values ("Line Out" and "Line In")

Test voltage	2,000 V 1 min
Surge strength	according to CEI, Publication 60 4000 V 1/50
Reflection	20% at 600 real value
Symmetry damping	6.5 N
Transmission power	adjustable according to local regulations

(1) Up to 24 x 8 channels may be used for transmission in the normal frequency range.

(2) Up to 12 x 8 channels may be used for transmission in the special frequency range. This frequency range has to be employed if the transmission line is also being used for voice transmission. In this case, additional filters must be fitted.

Appendix B/ Findlay Irvine Ltd. – Technical Specification

B.1/ Out-station Information

Each out-station has an address maximum of six channels. The total availability from each out-station is four analogue and 2 x 8 switched levels. Each out-station will provide the following information and data signals:

Road Surface Temperature – Over the range of -20°C to +20°C
Air Temperature – Over the range of -20°C to +20°C
Wind Speed (optional) – Over the range 0 to 100 knots
Wind Direction (optional) – Zero to 360°
Status Information
- Normal – Road wet or dry and a surface temperature above 2°C
- Alert – Road wet or dry and a surface temperature of below 2°C
- Critical – Road wet with moisture or a salt solution and about to freeze, 1 BIT
- Ice – Road icy, 1 BIT

Moisture – Wet or Dry, 1 BIT
Salt Solution – Present or not present, 1 BIT
Out-Station Identification, Check Channel – Two B.C.D. pre-set codes, 8 BITS
Channel Availability – Four switched channels available for future use, 4 BITS

B.2/ Telemetry

These signals are applied to our telemetry modules which provide audio frequency shift keyed tones (FSK) after their corresponding addresses have been received. The address from the master station and information reply is transmitted as a 12 bit serial code at a BIT rate of approximately 300 per second. For the communication link, the signal amplitude is 2V peak to peak approximately and the link used would have to convey this information between stations. The output may be arranged to feed and control a radio Tx/Rx unit or be connected to a two wire communication link.

B.3/ Information Up-Date

Four seconds for twenty addresses.

B.4/ Addresses Available

Up to 10, 20, 40, 80 or 100 max.

B.5/ Power Requirements

Signal Processing Unit – 110, 220, 240V, 50/60Hz, 150 W
Radio Cabinet (if required) – 110, 220, 240V, 50/60Hz, 150 W
Cabinet Heater – Each cabinet is provided with a thermostatically controlled anticondensation heater of 100 W

B.6/ Physical Parameters

B.6.1/ Out-station Signal Processor Unit

Eurocard modular construction for easy maintenance and spares. Portable and plug-in. Monitor points and LED indication on Eurocard plug-in modules where relevant (see functional diagram).

– 1 ft. 2.5 in. (365 mm) x 11 in. (280 mm) x 9 in. (230 mm)
– Weight 17 lb. (18 kg)

B.6.2/ Weatherproof Cabinet

– Incorporating back-plate, terminal strip, anti-condensation heater and mains isolator.
– 1 ft. 8 in. (550 mm) x 2 ft. (610 mm) x 10.5 in. (265 mm)
– Weight: 39.6 lbs. (18 kg)

B.6.3/ Radio Weatherproof Cabinet (when required)

– Incorporating radio, back-plate, terminal strip, anti-condensation heater and mains isolator.
– 1 ft. 8 in. (550 mm) x 2 ft. (610 mm) x 10.5 in. (265 mm)
– Weight: 35.2 lbs.

B.6.4/ Ground Sensor Assembly

– Detecting surface temperature, moisture, snow/ice and salt.
– 1 ft. 1 in. (330 mm) x 1 ft. 8 in. (500 mm) x 1.75 in. (45 mm)
– Weight: 20 lbs.

B.6.5/ Air Sensor Assembly

– Incorporating temperature probe in free air housing.
– Colour: Gloss White.
– 7 in. (180 mm) x 10 in. (255 mm) x 3.5 in. (90 mm)
– Weight: 2.2 lbs. (1 kg.)

B.6.6/ Aerial Mounting Pole (when required)

– Frangible aluminum.
– 7 ft. (1.13 M) x 1.5 in. (40 mm) dia.
– Weight: 4.4 lbs. (2 kg)

B.6.7/ Mounting Base for Aerial Pole (when required)

– Galvanised steel.
– 1 ft. (310 mm) x 8 in. (200 mm)(Bottom Plate).
– 1 ft. 2 in. (355 mm) x 2.5 in. (65 mm) dia. socket attached to plate.

B.6.8/ Tx/Rx Aerials (when required)

To suit frequency allocation.

B.7/ Master Station

B.7.1/ Control Unit

• Each out-station channel is interrogated by the control unit in sequence.

• Each channel has an allocated two digit address from 00 to 99.

• Addresses available – 10, 20, 40, 80 or 100 max.

• Address signals are encoded and applied to our telemetry modules which provide audio frequency shift tones (FSK).

• The interrogation signal is transmitted as a 12 bit serial code at a BIT rate of approximately 300 per second. This signal initiates a response from the out-station and the reply is decoded by our decoder modules to provide data for the alarm unit and the microprocessor of the VDU. For the communication link the signal amplitude is 2V peak to convey this information between stations. The output may be arranged to feed and control a radio Tx/Rx unit or be connected to a two wire communication link.

• Information update – four seconds for twenty addresses.

• The control unit and alarm unit operates independently of the microprocessor and VDU making its data available on an 8 BIT tri stated data bus line controlled by two lines: data request, and data valid.

• Eurocard modular construction for easy maintenance and spares. Portable and plug-in. Monitor points and LED indication on Eurocard plug-in modules where relevant (see functional diagram).

– 1 ft. 8 in. (500 mm) x 1 ft. 7 in.(480 mm) x 8 in. (200 mm)
– Weight: 28.6 lbs (13 kg)

B.7.2/ Alarm Unit

– Incorporating audible and visual critical warning circuits with delayed ON and OFF initiation to prevent spurious alarms.
– Portable.
– Suitable for wall mounting.
– Complete with connecting cable.
– 4.25 in. (120 mm) x 2.25 in. (70 mm) x 1.5 in. (45 mm)
– Weight: 12 ozs. (300 g)

B.7.3/ Information Display Equipment

A visual display unit with its own keyboard, memory banks and microprocessor.

The information from the control unit is displayed on a 9 in. (230 mm) screen with green fluorescent phosphor. The data is formatted to provide information on the location and status of each out-station 1. Subsequent pages graphically display a historical record of surface temperature over the past hour in steps of 0.2°C. Real time and date displayed continuously.

Automatic scrolling of surface temperature axis in 4°C bands over the range.

Programme supplied initially on magnetic cassette complete with recorder, subsequently on pre-programmed RQMs. Programme provides for manual or automatic operation of printer. Non-user keys are locked out by the programme. Programme provides automatic data link check on out-station identification check channel.

– 1 ft. 7 in. (480 mm) x 1 ft. 5.5 in. (445 mm) x 1 ft. 4 in. (410 mm)
– Weight: 28.6 lbs. (13 kg)

B.7.4/ Printer

– Prints out all data displayed on screen, including graphics. Initiated by programme or by pressing 'P' on the keyboard.
– 1 ft. 2 in. (350 mm) x 10 in. (250 mm) x 4 in. (100 mm)
– Weight: 11 lbs. (5 kg)

B.8/ Power Requirements

Master Station Equipment – 110, 220, 240 V 50/60 Hz 50 W

Radio (if required) – 110, 220, 240 V 50/60 Hz
42 W

Aerials Tx/Rx – To suit frequency allocation

Purpose made desk to house Master Station
Equipment – Optional

Appendix C/ Surface Systems Inc. – Technical Specifications

C.1/Output

The display monitor indicates conditions of "clear", "wet", "alert" or "ice" by coloured lights on the panel. Air temperature and surface temperature are indicated by solid-state digital display. There is an audible alarm for the condition of "alert" and "ice". A monitor will accommodate a maximum of five sensors. The "alert" status indicates light frost or snow and a wet surface prior to freezing. "Ice" status indicates ice, frozen packed snow and heavy frost.

A single channel monitor is available.

C.2/ Surface Condition Status Information

The following states are detected, displayed and printed:

Dry – No moisture present on surface.

Wet – Wet surface above 0°C.

Dew – Moisture present on surface. Surface temperature equal to or less than dew point and above 0°C.

Frost – Moisture present on surface. Surface temperature equal to or less than dew point and equal to or below 0°C.

Frost Above Dew Point – Previously frost, but surface temperature now moved above dew point.

Absorption – Absorption of moisture into chemicals on the surface. Appears dry or slightly damp. Surface temperature above dew point.

Absorption at Dew Point – Absorption of moisture into chemicals on the surface. Appears drier or slightly damp. Surface temperature at dew point.

Surface Alert – Precipitation/moisture present in liquid form on surface. Surface temperature at or below 0°C.

Surface Critical – Surface temperature at or below 0°C.

a) Precipitation/moisture in liquid form on surface starting to freeze;
b) Precipitation/moisture on the surface which has frozen.

Probably Drying – No precipitation detected in last four hours, no chemical present and surface temperature is rising.

C.3/Sensor System

C.3.1/ Components

- Sensor head 2.9 x 12.7 cm.
- In-line driver unit, approximately 8 m from the sensor head 20.3 x 10.2 x 7.6 cm.
- Remote processing unit which contains the power supply, logic circuits and output circuits. 40.6 x 35.6 x 15.2 cm.

C.3.2/ Sensor Head

- Molded of epoxy. Sampling of surface conditions is by a non-destructive method in that no heat is present in the sensor head. The sensor head was designed with similar thermal characteristics as commonly used highway materials.
- The head will withstand the maximum of 2461 kg/cm (35,000 psi) compressive load.
- Distance from sensor to driver unit – fixed at 8 m.
- Distance from sensor driver unit to processor unit – 150 m maximum.
- Cable required is three-pair shielded of minimum No. 22 wire.
- Distance from remote processor unit to display monitor – the SSI telemetry method allows long distance transmission on a single pair of telephone lines to the display monitor. The monitor sensitivity is such that it will work with a 180 dB signal loss from the remote processor unit location.

C.3.3/ Temperature Operating Range

System will provide stable operation over a temperature of 30°C to 80°C.

C.3.4/ Sensitivity

Adjustable – can be set to detect slightest amount of frost or snow or to detect only thick water, ice or hard-packed snow.

C.3.5/ Temperature Accuracy

High accuracy thermistors are used in the sensor head to measure surface temperatures. The thermistor accuracy is ±0.2°C over a range of -20°C to 80°C. Temperature readouts on the monitor are available in Celsius or Fahrenheit degrees.

C.3.6/ Circuit Construction

High quality TTL's and CMOS integrated circuits are used throughout. The entire system uses solid-state components with no mechanical or moving parts.

C.3.7/ Display Monitor

Dimensions: 27.9 x 27.9 x 16.5 cm.

C.4/ Power Requirements

Remote Processing Unit – 110/220 VAC, 60 Hz, maximum 200 W load.

Control Processing Unit – 110/220 VAC, 60 Hz, maximum 500 W load.

Appendix D/ Summary of State Field Testing of Devices (November, 1971)

State	When Tested	Devices Tested	Comparitive Testing	Meteorological Data Collected	Warning Sign Connected?	Alerted Maintenance Crews	Communication Media	Other Counter Measures	Reports Published	State's Comments on Tests
Arizona	1970-present	Econolite	No	No	Yes	Yes	Radio	None	Planned for 1972	Some problems with sensors.
Arkansas	1968	Econolite	Unknown	Unknown	Yes	No	Direct Wire	None	0	Unsatisfactory. Sensors failed
California	1968-present	Econolite Holley Nelson	No	Pavement Temperature	Temporarily	Yes †	Telephone	Electric Heating Coils	2	Unsuccessful in detecting frost.
Colorado	1965-66	Econolite	No	Yes	Yes	No	None	None	1	Satisfactory.
Idaho	1970-present	Econolite	No	No	Yes	No	Direct Wire	None	0	Unsatisfactory. Problems with sensors.
Illinois	1970-present	Holley	No	No	Yes	Yes †	Direct Wire and Telephone	None	0	Unsatisfactory. Electronic component failure.
Iowa	1964-present	Econolite Icelert Cytronic	No	Air Temperature	No	Yes	Radio	None	1	Satisfied with cytronics device.
Kentucky	1967-present	Econolite Icelert	Unknown	No	Yes	Yes †	Radio	None	0	Communication failure.
Maine	1962	Econolite	No	No	Yes	No	Direct Wire	None	0	Unsatisfactory. Equipment failure.
Michigan	1964-68 and present	Econolite Holley (several)	Yes	Partial	Temporarily	No	None	None		Satisfactory.

cont...Appendix D/ Summary of State Field Testing of Devices (November, 1971)

State	When Tested	Devices Tested	Comparitive Testing	Meteorological Data Collected	Warning Sign Connected?	Alerted Maintenance Crews	Communication Media	Other Counter Measures	Reports Published	State's Comments on Tests
Nebraska	1970-present	Econolite	No	Unknown	No	Yes	Direct Wire	None	Planned	Sensor and electronic failure.
North Dakota	1969-present	Hinrichs	No	No	No	No	None	Salt Spreaders	0	Unsatisfactory. Spreaders clogged and replaced sensors.
Ohio	Early 1960's	Kar Trol *	No	No	Yes	No	None	None	0	Unsatisfactory. Too many false alarms.
Oregon	1964-65 and 1969-present	Kar Trol * Holley	No	No	Yes	No	Direct Wire	None	0	Unsatisfactory. Sensor and electronic failure.
Pennsylvania	1969-present	Econolite	No	Yes	No	No	None	None	1	Unable to detect frost.
Virginia	1969-present	Econolite Icelert Holley (planned)	No	No	Yes	Yes	Radio	None	0	Not completely satisfactory.
Washington	1963-present	Unknown	No	No	Yes	No	Direct Wire	None	0	Satisfactory.
West Virginia	1965-70	Unknown	Unknown	No	No	Yes	Radio	None	0	Satisfactory.
Wyoming	1963(approx)	Econolite	No	No	Yes	No	Direct Wire	None	0	Unsatisfactory. Sensors failed.
District of Columbia	1971 (planned)	Holley	No	Partial	Yes	Unknown	Direct Wire	None	0	

† State highway police receive the warning signal and in turn notify the state highway maintenance crews.
* Kar Trol, ice-snow-frost detector is the forerunner of the current Econolite device.

Appendix E/ Early Ice Detection Devices

Econolite Ice-Moisture Detector
Uses conductance to determine wetness, thermistor for temperature. Gives 'wet' and 'ice' indication. Two probes are used, one heated, one not.

Hinrich's De-icer System
Detects ice, snow and especially frost and activates countermeasures. Based upon four probes each of which measure temperature and three of which measure moisture.

Holley Highway Ice Condition Detection System
Two modes of operation. One detects ice and snow. Other predicts frost. Uses three probes; one for air temperature and relative humidity, and two road probes, one heated, one not. Probes use thermistor for temperature and measure resistance for moisture.

Icelert Ice Detection Systems
Basically have three systems. Most relevant is Road Ice and Salinity Detector. Uses multiple probe sensing pavement temperature, heated moisture probe, unheated moisture probe, and probe for salinity measure.

Cytronics Ice, Snow and Frost Detection System
Uses one probe to which a programmed heating current is applied and temperature sensing thermocouple. Operates on principle of phase change and latent heats. Developed by Iowa DOT. Basically frost detection only. Problems if heavy snowfall.

Nelson Road Ice Detector
Uses sensors for pavement temperature, air temperature and moisture. Temperature sensors are switches. Moisture sensor is based on resistance.

ASEGA Ice Warning System
Uses thermistor to measure roadway temperature and conductivity/resistance to sense moisture.

Battelle Ice Warning
Use temperature sensitive reflectors which change colour to indicate outside air temperature to motorists.

Highway Guard
Uses two road sensors for temperature on road and on adjacent precipitation collector. Can't detect frost or handle salinity.

Hydro Dynamics Street and Ice Alarm System
Uses two sensors, one for temperature and one for moisture. Not specifically for road use. Can't detect frost or deal with de-icing chemicals.

Industrial Nucleonics Water and Icing Detection System
Detects scattered radiation from radio-isotope source on road surface. Not very selective, and probably has calibration difficulties.

Meteorological Institute of Munich University Warning System
Uses three sensors. One road mounted temperature sensor and two pedestal mounted moisture sensors, one heated, one not. Very poor accuracy.

Mourgeon Ice Warning Device Type B1000
Uses sensors to measure road temperature and conductivity to assess moisture (i.e., like Icelert, ASEGA, Econolite).

Rails Company Snow Detector
Senses temperature not precipitation. Designed for detection of snow near railway switches. Can't detect frost. Not de-icing chemical resistant.

Richard Device
Senses road temperature and relative humidity of atmosphere. Results very poor.

Road Research Laboratory Systems
Early system tested 1961/62. Two sensors measure road temperature and conductance. Temperature ony noted as greater or less than freezing. Also includes heating element. Can't detect frost. Reliability affected by chemicals.

Rosemount Ice Warning System
Uses a small vibrating bar whose natural frequency is affected by ice accretion. Not suitable for road application.

Ruprecht Warning System
Three sensors measure road temperature, air temperature and relative humidity. Very poor accuracy.

Sharp Ice Detection System
Utilized modelling approaches to predict future pavement temperatures. Three sensors measure pavement temperature, moisture (conductivity) and light scatter (three temperature levels and two conductivity levels only). Still being developed. Expensive.

Statens Vaginstitut Frost Indicator (National Swedish Road Research)
Two devices. One uses three sensors to measure pavement temperature, air temperature and relative humidity. Other device is mechanical and measures sliding friction on road surface.

Neither device suitable. Logic problem with sensor device. Placement problem with mechanical device.

Sunbeam Precipitation Detector
Measures capacities between adjacent plates. Moisture in air changes di-electric properties. Measured dissipation factor to determine if ice or water was present. Not suitable for road use.

Vag Thermo Device
Senses road temperature and atmospheric related humidity. Poor results.

Scan System
Measures change in capacity to detect moisture and change in conductivity to discriminate between ice and moisture.

Honeywell
Radiometer based method. Measures spectral temperature at 1.6 cm wave length (product of actual temperature and surface emissivity).

Nelson Snow Detector
Detects ice by sensing surface temperature below 32°F and conduction of a heated probe.Cannot compensate for presence of de-icing chemicals.

Lockheed Missile and Space Co. Microwave Radiometer
Based upon a radiation receiver capable of detecting electromagnetic radiation of objects occurring as a result of their temperature being greater than absolute zero. Requires pavement temperature sensor. Considered FHWA in 1979. Discontinued.

Dupont Hydrometer
Details not available.

Kar-Trol
Forerunner of Econolite system. Superceded.

Appendix F/ Summary of Ice Detection and Road Weather Information Systems Study Contacts

In addition to literature sources quoted elsewhere, a number of personal contacts were made in an effort to overcome the scarcity of published data on this subject. These contacts are given below, with a description of their experience with RWI systems.

F.1/ States in the U.S.

Arizona
- One previous ice detection device was installed.
- Results were less than satisfactory.
- Do not feel such systems are cost-effective as maintenance forces are aware of trouble spots.
- No current or planned installations.

California
- Previously had an installation, very early battery powered system.
- Experienced poor reliability many problems.
- System abandoned.
- No current or planned installations.

Colorado
- Had a system in place approximately 10 years ago.
- Also have a Scan 7000 system in a viaduct.
- No formal evaluation of the system has been made.
- Installing Scan 16 system on highway.

Idaho
- Previously had a system during early 70's.
- Operation was not acceptable, poor reliability.
- System abandoned.
- Currently working with Surface Systems Inc. to have a Scan 16 system installed for winter 1985-86.

Illinois
- Had an old Scan system about 10 years ago.
- System didn't work well, also problems with radio interconnection.
- System was removed when bridge deck rebuilt.
- Also have one Scan 16 system currently in operation.
- System had dedicated phone lines, still experiences problems.
- System relocated and upgraded, better results but still problems of down time, erratic data.
- Generally like ice detection but still need to use road patrols.
- New system still being evaluated.
- To install Boschung system for winter 1985/86.

Indiana
- Currently installing a Boschung system on a bridge deck.
- System not yet operational, no evaluation available.

Iowa
- No recent system.
- No system currently in operation.
- No plans for installation in the future.

Kentucky
- About 15 years ago had an installation of a Dupont Hygrometer.
- System no longer in operation.
- No plans for future installation.

Maine
- Had installation of Scan 7000 system in 1980.
- Satisfied with system in operation, no major problems.
- System accuracy approximately 90%.
- No current plans for expansion, upgrading.

Michigan
- Completed trial installation of Scan 16 system in January 1983.
- A number of initial difficulties were encountered, especially software revisions and some minor equipment failure.
- After initial period system performed well with good accuracy.
- Reluctance to rely solely on system, operator intervention is considered necessary.
- Also installing a Boschung system in Oakland County on a free two year trial basis for evaluation (Boschungs first North American system).

Montana
- Had a Scan 7000 system installed in June 1980.
- System failed to operate acceptability.
- Scan 7000 upgraded to Scan 16 in February 1984.
- Performance has been satisfactory but system operating costs exceeded expectations.
- System has been relocated for further evaluation.

Nebraska
- Installed a Scan 7000 system approximately 10 years ago.
- Late in 1984, a further Scan 16 system was installed on a bridge deck.
- Due to late installation no evaluation has been completed.
- Interested in doing further evaluations of ice detection equipment.

Nevada
- Installed a Scan 7000 system in a tunnel about seven years ago.
- Operation was unacceptable, very poor reliability.
- Some problems may be due to tunnel location.
- System upgraded to Scan 16 but operation still poor.
- System has been re-installed to a bridge.
- No formal evaluation completed.

New Jersey
- Have four installations of Scan 16 equipment.
- Equipment not used during winter 1984/85 due to unavailability of telephone lines.
- Hope to establish system during 1985 using radio interconnection.
- Installations are on bridge decks but system is to be used for both spot hazard and early warning.
- To be evaluated winter of 1985/86.

North Dakota
- One installation 10 to15 years ago.
- Operation unsatisfactory, system abandoned.
- No current or planned systems.

Ohio
No current state installation.

Oklahoma
- Had an old installation 10 to 15 years ago, but system now abandoned.
- No current operational systems.
- Have contracted to install a Boschung and Scan 16 system for side by side comparison during winter of 1985/86.

Oregon
- Have installed Scan system at three locations on bridge decks, telephone interconnection.
- Installation completed in July 1981 at a cost of $133 000.
- Annual maintenance contract provided by SSI at a cost of $14 000.
- Use primarily to detect spot hazards, also for system wide indication. One installation includes motorist advisory signs.
- System is very reliable and accurate.
- Very satisfied with overall operation.

Virginia
- Have tried a variety of ice detection equipment in the past, no systems are now operational.
- Planning to install a Scan system for trial during winter of 1985/86. (Turnpike Authority).

West Virginia
- Tried to install a system in late 70's but never completed installation.
- No systems currently in use and none planned.

Wyoming
No current application of ice detection equipment.

F.2/ U.S. Cities

Columbus, Ohio
- The City of Columbus installed a Scan 7000 system in late 1981.
- Operation was not satisfactory, system upgraded to Scan 16 in 1983.
- Sensors are on a bridge deck.
- No formal evaluation done but visual comparison of road condition and sensor output indicate response is accurate.
- Initial installation cost was $40 000. in 1983.
- Maintenance costs are low but telephone line rental is very expensive.
- Ohio office of FHWA is not satisfied with system accuracy.

Chicago, Illinois
- Scan system installed 1982 on one structure.
- Installation cost estimated to be $35 000. but free installation and one year maintenance from supplier for trial.
- Used in conjunction with Federal radar system. Use radar to follow storm and ground sensors to monitor location and ground conditions.
- System evaluation is still underway, but generally satisfied.
- Planning to expand system.

St. Louis, Missouri
- Have Scan equipment installed during 1981/82 at six locations, five are bridge decks and one is an isolated location intended to monitor flood risk.
- Very satisfied with system reliability, no formal assessment made.
- Use detectors to warn of spot hazards only, they do not give reliable results for system wide application.
- Do not man system 24 hours a day but use modem and printers installed at home to monitor conditions.
- Feel that system is cost-effective, second snowfall with system they saved $34 000. due to avoiding salt runs.

Springfield, Missouri
- Had a previous Scan 7000 ice detector installation with warning signs.
- Operation was very unreliable and unacceptable.
- System abandoned.
- No plans to develop new systems.

Washington D.C.
- No current road installations, use weather detection system to activate heated pedestrian walkways.
- Have one bridge installation but very old, generally satisfied.
- Do not require additional road data due to compact area adequacy of road patrols and purchased weather forecasting service.

Multinomah County, Oregon
- Installed Scan road sensors only about two years ago on bridge deck.
- No weather sensing equipment.

- Note high reliability, satisfied.
- No plans for expansion.

F.3/ Canada

Pearson International Airport

- Scan and Icelert systems installed for one year trial period for 1982/83 winter season.
- Some initial difficulties but acceptable in view of developmental application.
- Main problem was inability to discern between total ice coverage and isolated icing.
- Both systems operated comparably, slightly more satisfied with Icelert.
- Do not feel that ice detection system is cost-effective as continuous 24 hour surveillance of runway condition is made.
- Implementation and realization of staff related benefits may be difficult due to union environment.

F.4/ Europe

University College, Swansea

- Noted comparison testing of various equipment underway in Europe.
- U.K. uses spot detection primarily due to climate, frequency of freeze thaw cycle.
- Placement of road sensors is determined by runs using an infra-red thermameter to generate road temperature profiles.
- Selection of road sensor locations is still a problem, however.
- Road detection systems are used to determine salt spreading routes and to assist maintenance call out decision.
- Maintenance call out decision is made at county/ district level.
- Also uses weather radar to observe upcoming weather patterns.
- Feel such system development in Europe is technically ahead of North American development.
- Noted difference between U.K. and Finnish application is due to climate, weather data availability, level of maintenance call out decision (i.e., local or national).

Sweden

- Road maintenance standards and decisions are made at the national level by a central advisory organization.
- They have been implementing a large system for the past three to four years and plan to continue expansion in the next five years.
- Reasons for developing an extensive roadside weather monitoring network:
  - Conditions vary dramatically in the road network.
  - Few good weather radars existing, hence limited accurate weather forecasting.
  - Weather forecasting is provided at the national level.
  - Need for as much information as possible to guide local roadmasters.
- They do not use road sensors extensively to detect ice as accuracy is limited. Road sensors are use to detect moisture and temperature and weather data is added to determine critical freezing conditions.
- They are planning to install some roadway ice detectors for evaluation during this coming winter season.